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RESEARCH TRIANGLE INSTITUTE
Durham, North Carolina
FINAL REPORT: PART I
R-OU-81

Analysis of Survey Data

E. L. Hill, W. K. Grogan,
R. O. Lyday and H. G. Norment
15 February 1964

Prepared for
Office of Civil Defense
United States Department of Defense
under
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Sub-task 1115A


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RTI Project OU-81

by
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PREFACE

This is Part I of two separately bound parts of a report which describes the research completed under the Office of Civil Defense Sub-task No. 1115A, Analysis of Survey Data. This part summarizes the conclusions and recommendations as well as the principal investigations undertaken in meeting the objectives of the sub-task.

Part II contains the appendices which give supplemental details regarding computer programs, analytical methods, computational schemes, subsidiary recommendations, etc., necessary to accomplish the contract objectives. An abstract for each part is presented on the following pages.

The authors would like to acknowledge the valuable assistance received from Dr. Wesley O. Doggett, Consultant (Professor of Physics, North Carolina State of the University of North Carolina at Raleigh), in the review of research and formulation of computational procedures; from Dr. Donald T. Searls of the RTI Statistics Research Division in the statistical phases of the project; and from Donald R. Whitaker for his editorial assistance in preparation of the final report.

Contributing to the project as members of the team were Elizabeth Carroll, Patricia Craig, Carolyn Parker, and Judy Suor.

Dr. H. Norment, who is listed as an author of this report, contributed during the first half of the project. Accordingly, he has not had an opportunity to review the presentation of his research results.

ABSTRACT FOR PART I

This is Part I of two parts reporting the analysis of data collection and protection factor (PF) computational procedures used in the National Fallout Shelter Survey (NFSS), under OCD Sub-task 1115A, Analysis of Survey Data. The probable error in the NFSS Phase 1 PF is estimated by surveying a probability sample of 33 NFSS Phase 1 buildings and comparing NFSS PF's with both Engineering Manual (EM) computations and with PF's from RTI-prepared FOSDIC (Film Optical Sensing Device for Input to Computers) forms. The primary objective of this sample survey of buildings was to determine what change in PF would occur if more sophisticated procedures, such as those of the EM, were used in the NBS-NFSS Computer Program. The architect-engineering (AE) Phase 1 PF's for this sample of buildings containing PF Category 2-4 shelters are found to be conservative by an average of 99 PF units when compared to the EM PF's; however, data are variable and four are nonconservative because of differences in RTI and AE input data. Other comparisons indicate that: (1) AE Phase 1 PF's are an average of 22 PF units higher than those using an RTI prepared FOSDIC form; (2) EM PF's are an average of 110 units higher than the RTI FOSDIC PF's; and (3) EM PF's are lower by approximately a factor of 2 when compared with full-scale experimental results for four buildings. Estimates of average differences for individual elements of AE and RTI FOSDIC input data are also presented.

The conservative bias and variability of PF estimates indicated on the Phase 1 printout are of great significance to those doing vulnerability analyses using NFSS data.

As a part of the building sample survey, RTI estimates an average of 2.96 gallons of trapped potable water available for each PF Category 4 or better shelter space.

Further, NFSS Phase 1 structures are categorized with respect to technical shielding characteristics using a statistical sample of 1541 buildings. This is shown by analysis of FOSDIC structural input data, and relating it to the Phase 1 PF.

New information on shielding is analyzed to determine if existing methods for computing protection factors need modification to agree with new data; recommendations for shielding research are made.

Recommendations for changes in the NBS-NFSS Computer Program method of calculating radiation contributions are made for exposed basements, roofs, stories above grade, and areaways. These changes bring the program closer to EM procedures while still using only NFSS Phases 1 and 2 data.

ABSTRACT FOR PART II*

This part contains sixteen appendices (A-P) to the chapters of Part I of the final report for OCD Sub-task 1115A, Analysis of Survey Data. These appendices contain details of computer programs used in categorization of structures with respect to technical shielding characteristics and resultant tabulations (A-E); details of the RTI 33 NFSS Phase 1 building sample selection method (F); an illustration of procedures used in identifying building elements critical to PF computations (G); RTI computational method and forms used in making Engineering Manual PF calculations for the 33 sample buildings (H); descriptions of the 33 buildings, the five PF results (AE Phases 1 and 2, RTI FOSDIC with and without partitions, and Engineering Manual), and analyses of individual building input and procedural differences judged to have affected the PF differences (I); construction details of four buildings used in comparing experimental and calculated PF's (J); trapped potable water field data gathered in the 33 building survey (K); detailed analyses of Technical Operations Research reports that affect the procedures used to calculate PF's (L-N); a summary of conclusions and recommendations made by Technical Operations Research and concurred with by RTI (O); and detailed recommended modifications to the NBS-NFSS Computer Program (P).

* E. L. Hill, et al. Analysis of Survey Data. Part II - Appendices (Final Report on OCD Sub-task 1115A). Durham, North Carolina: Operations Research Division, Research Triangle Institute, 15 February 1964.

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Chapter 1

Summary

I. SCOPE AND OBJECTIVES

This constitutes the final report of the research completed by the Research Triangle Institute under Office of Civil Defense Project 1115A, Analysis of Survey Data. The OCD description for this project is as follows:

"Review the National Fallout Shelter Survey findings to estimate probable error, or reliability in the light of existing experimental data and theoretical considerations. In consultation with the Subcommittee on Shielding of the Advisory Committee on Civil Defense, categorize the surveyed structures with respect to technical shielding characteristics, and evaluate the feasibility and importance of developing special computational programs for the several categories determined. Evaluate new information on shielding for application to the computation of protection factors for surveyed structures. Accomplish reprogramming or additional programming of computational procedures for analysis of the survey data."

The survey data requiring analysis under this project consist of many types of information collected, recorded, manipulated, summarized, and reported in Phases 1 and 2 of the National Fallout Shelter Survey (NFSS). Five million structures with potential shelter space were covered by the survey and data were actually collected in Phase 1 for approximately 375,000 of these. Over 600 architectural and engineering (AE) firms were responsible for collecting this mass of data in approximately six months' time.

The existing structures surveyed in the NFSS failed to yield enough 100 PF or better spaces to shelter the nation's population. Allowing for population growth and movement between home and work, an additional 170 million shelter

spaces will be needed by 1968 (Reference 1)*. This shelter deficit must be met by a combination of subsidized and unsubsidized shelter space in privately owned facilities, by shelters in federal civilian and military buildings, and by home shelters.

NFSS procedures were generally designed to give conservative results, i.e., to underestimate the PF. It is expected that many additional adequate spaces could be identified if the computational procedures were made less conservative in order to yield results closer to the true PF.

The objectives of this project were to analyze the NFSS findings and to evaluate new information on shielding in order to identify feasible modifications of the NBS-NFSS Computer Program (References 2 and 3). This could reduce substantially the deficit of shelter spaces with a very nominal expenditure of funds.

It should be noted that RTI found a conservative bias and substantial random errors in PF computations reported in NFSS Phases 1 and 2. Although beyond the scope of this study, the impact of the probable errors of the NFSS findings on other civil defense activities is recognized. They are of great significance to those using these PF estimates in vulnerability analyses and related areas of study (need for decontamination, need for additional shelter or shelter modifications, speed of radiological recovery, etc.).

* References are found at the end of each chapter.

II. APPROACH AND FINDINGS

The OCD project description was divided into four tasks by the Research Triangle Institute. The four tasks were: (1) analyze the NFSS findings to determine probable error; (2) categorize surveyed structures with respect to technical shielding characteristics; (3) evaluate new information on shielding; and (4) recommend changes, when justified, to the computational procedures for analysis of the survey data. An outline of the approach used by RTI in accomplishing these tasks and major findings are as follows:

1. Analysis of NFSS Findings. RTI evaluated the NFSS findings to determine the probable error by surveying a probability sample of 33 buildings. The primary objective of this survey was to determine what change in protection factor would occur if procedures, such as those of the Engineering Manual (Reference 4), were used in the NBS-NFSS Computer Program (References 2 and 3). Using data collected by RTI, a Phase 1 FOSDIC* form was prepared for each sample building and submitted to the National Bureau of Standards (NBS) for processing with the NBS-NFSS Computer Program. Comparison of results from the RTI FOSDIC with the Engineering Manual computations indicates changes in computed protection factors due to procedural differences. The Engineering Manual computations for the sample buildings showed an average difference of 110 PF units higher than the PF's calculated by the computer using the RTI FOSDIC.

A secondary objective of the survey was to determine the accuracy of the input data of the NFSS. This was necessary in

* Film Optical Sensing Device for Input to Computers

order to determine the procedural differences and to estimate the reliability of future calculations using existing input data. Input differences were estimated by comparing the original AE prepared NFSS Phase 1 FOSDIC inputs and printout results with NBS-NFSS computations using data submitted by RTI on FOSDIC forms. Comparison of these results indicated that the AE PF's were an average of 22 units higher than those using the RTI FOSDIC. Comparison of the original AE Phase 1 FOSDIC results with Engineering Manual results indicates that the Phase 1 results are lower by an average of 99 units.

As examples of specific data input differences, AE data inputs for upper wall mass thickness were an average of 21 psf higher than RTI estimates and the first floor mass thickness was an average of 15 pounds higher. These results were very surprising, since it was felt at the beginning of the project that the AE's would consistently tend to be conservative when evaluating building data. The AE Phase 1 PF results were higher than Engineering Manual results for four of the sample buildings and equal for two others.

Details of the sample selection, field survey procedures, computational procedures, building structural characteristics, and all results are given in Chapter 4 and Appendices F-I.

As a part of this task, an evaluation of the accuracy of the Engineering Manual procedure was made by comparing theoretical results with those obtained experimentally using the "pumped source technique." A comparison was made for four buildings,

and the results were close enough in most cases that modest weights assigned to interior contents would make them agree. Details of this analysis are given in Chapter 5 and Appendix J.

2. Categorization. The categorization of surveyed structures with respect to shielding characteristics was accomplished by a statistical sample of 1541 buildings drawn from the more than 300,000 buildings actually surveyed. The sample was selected from the NBS Phase 1 M1 and M2 files, and statistical studies on detailed structural properties were made. Statistical tabulations were prepared relating protection factor to the number of shelters and buildings falling within selected incremental ranges of properties such as story number, percent apertures, contaminated plane width, floor area, basement exposure, dose source, and others. The detailed structural input data and PF output data for the sample of 1541 buildings are available on magnetic tape for any additional categorization which may become desirable. Details of the computer programs used and the statistical tabulations are contained in Chapter 3 and Appendices A-E.

For this sample of buildings, 39 percent of the shelters are in the basement. The mean story number varies from three to four for all PF categories except Category 8, where it jumps to six. The average percent of apertures for buildings in each PF category ranges from 15 to 19 percent. The vast majority of the shelters, 78 percent, have an area in

the range of 1,000 - 10,000 square feet. Only 17 percent of the total shelters are found to have interior partitions reported. The modal value of the exterior wall mass thickness falls in the range of 100 - 150 psf. Eightypercent of the sample buildings have only one part reported, 12 percent have two parts, and 4 percent have three parts.

3. Research Review. The objectives of this task were to determine whether existing methods for computing protection factors need modification to agree with new data; to recommend new investigations in areas where gaps exist in current shielding knowledge; and to suggest applications of new shielding information to problems confronting the Office of Civil Defense. This task was accomplished by visits to contractors engaged in shielding research, by personal contacts, and by a literature search.

Major findings of this review of shielding research are:

- a. The roof contribution and infinite field contribution predicted by the Engineering Manual method for a concrete block house have been experimentally confirmed.
- b. The dose rates from finite planes of contamination indicate that the NFSS Computer Program and AE Guide (Reference 5) need revision.
- c. Experimental dose rates are higher than predicted in unexposed basements.
- d. Measurements of dose angular distributions support the use of an effective height in treating ground roughness.

- e. A new procedure based on experimental results is available for calculating ceiling shine.
- f. The Engineering Manual method of azimuthal sectors is adequate for handling interior partitions.

- 4. NBS-NFSS Computer Program Modifications. The results of the preceding tasks identified and justified feasible modifications to the NBS-NFSS Computer Program. Recommendations for changes in the machine method of calculating contributions for exposed basements, roofs, stories above grade and areaways are contained in Chapter 7 and Appendix P. Revised area factors and a method for considering the effect of interior partitions are also included in the recommendations. These changes bring the NBS-NFSS Computer Program closer to Engineering Manual procedures while still using only data collected in Phases 1 and 2 of the NFSS.
- 5. Survey of Available Potable Water. Although not one of the four major tasks, OCD asked RTI to obtain information on the amount of potable water "trapped" by plumbing, holding tanks, etc., in the 33 building sample used to study other NFSS characteristics. All drinkable water that was contained and covered (i.e., suitable for drinking in a fallout situation) was recorded. An average of 2.96 gallons per PF category 4-8 shelter space was found. Many of the buildings contained sufficient trapped water to supply the shelter for a 14 day period (3.5 gallons per person) without stocking of water containers.

III. RECOMMENDATIONS

A. Follow-up Work by RTI

The following would normally be recommendations, however the need for this work has already been recognized by OCD and a follow-on contract has been negotiated for OCD Projects 1115B and C. The project statements therein are as follows:

Project 1115B

"Analyze Phase 2 data from the NFSS to indicate relative importance of shielding characteristics in order to improve PF calculations and to indicate the most important modifications to improve PF. Utilize these data and studies of recurring types of key facilities under various geographic and construction conditions to identify the most critical engineering characteristics of the structure which would require modification for occupancy and operation in a fallout situation. Incorporate PF computational procedures for special characteristics of these key facilities in the electronic computer program."

Project 1115C

"Evaluate information on shielding, such as the effect of interior partitions, ground roughness, finite planes, apertures, ceiling shine, basement exposure, etc. for application to the computation of protection factors."

Additional analysis of area factors (defining the fraction of a story offering protection greater than a predetermined value) will be made under Project 1115B because present area factors ignore the effect of roof contribution.

B. Recommendations

The following recommendations for future work do not fall within the scope of work described in Paragraph A above. Additional secondary recommendations are to be found in the various chapters and appendices.

1. The NBS-NFSS Computer Program should be modified to bring it more in line with Engineering Manual procedures as outlined in Chapter 7.

2. Any computer programs for computing PF's where complex new building data are obtained should utilize the azimuthal sector procedures of the Engineering Manual (Appendix P).
3. Data collection in any updating procedure should make full use of building plans (Section III.F., Chapter 4).
4. Penetration data such as that presented in the charts in the Engineering Manual should be developed for the radiation of cobalt-60 and attenuation characteristics of steel (Chapter 6 and Appendix L).
5. An experimental and theoretical investigation should be made of the ground contribution to an unexposed basement (Chapter 6).
6. Technical Operations Research limited strip data should be compared with Engineering Manual calculations to verify Chart 9 therein (Chapter 6 and Appendix M).
7. The effect of cross partition (partitions perpendicular to the wall whose contribution is being considered) spacing on attenuation should be investigated (Appendix N).
8. The next revision of the AE Guide should carry the instruction contained in Section II. B. 2. of Appendix N of this report for treating cross partitions.
9. The Technical Operations Research procedure for computing ceiling shine should be incorporated in the Engineering Manual to be used for the class of configurations described in Section IV of Chapter 6 (Chapter 6 and Appendix O).
10. An investigation should be made of the influence on the wall barrier factors by slant penetration of radiation through walls in off-center azimuthal sectors (Section VI, Chapter 6).

11. The interior partition barrier factor for box-type interior partitions of mass thicknesses 20, 40, and 60 psf in a building with 80 psf exterior walls should be measured to determine the influence of the wall on the partition barrier factor (Section II. C. 2. of Appendix N).

REFERENCES

1. Office of Civil Defense. Highlights of the U. S. Civil Defense Program. Washington: Office of Civil Defense, Department of Defense, June 1963.
2. L. V. Spencer and C. Eisenhower. Calculation of Protection Factors for the National Fallout Shelter Survey. National Bureau of Standards Report No. 7539. Washington: U. S. Department of Commerce, July 1962.
3. National Bureau of Standards. Description of Computer Program for National Fallout Shelter Survey. National Bureau of Standards Report No. 7826. Washington: U. S. Department of Commerce, 15 March 1963.
4. Office of Civil Defense. Design and Review of Structures for Protection From Fallout Gamma Radiation. (Engineering Manual). Rev. ed.; Washington: Office of Civil Defense, Department of Defense, 1 October 1961.
5. Office of Civil Defense. Guide for Architects and Engineers. Washington: Office of Civil Defense, Department of Defense, December 1961.

Chapter 2

The National Fallout Shelter Survey (NFSS)

I. GENERAL

The title of OCD Project 1115A, Analysis of Survey Data suggests the need for familiarity with the National Fallout Shelter Survey. The purpose of this chapter is to describe the multitude of data collected in the NFSS and the conditions under which it was obtained.

The NFSS, which located fallout shelter space in existing structures, was the first and most important accomplishment of the new civil defense program. The data accumulated during the survey sharply reduced the estimated costs of long-term national and local shelter requirements.

The survey data provides local government, industry, and others with a planning tool which, for the first time, permits them to measure with precision the amount and location of existing shelter and thereby to estimate additional shelter required.

A requirement has been indicated for a total of 240 million PF Category 4 or greater shelter spaces by 1968, including an allowance for population growth and movement between home and work (Reference 1). The national survey initiated in fiscal year 1962 has identified shelter space expected to be made available for approximately 70 million people. Approximately 104 million spaces were actually identified but licenses to mark and stock will not be obtained for the entire total. Over the next five years, an estimated 20 million additional shelter spaces will be identified by the survey of new construction and major modifications of existing facilities.

This tremendous deficit of fallout shelter spaces emphasizes the need for computing protection factors with procedures yielding as nearly as possible the "true" PF. Experimental results analyzed by RTI show that the Engineering Manual method (see Reference 2) is the best procedure available. Even when such factors as interior contents are ignored, the PF is still underestimated by a large factor.

II. SURVEY ORGANIZATION

In administering the survey, the Office of Civil Defense called on assistance from the Bureau of the Census, the National Bureau of Standards, the Army Corps of Engineers, and the Navy Bureau of Yards and Docks. The latter two groups, in turn, contracted with professional architects and engineers throughout the country to conduct the necessary field work. Prior to the survey itself, special fallout shelter analysis training courses were conducted for architects and engineers (AE's) to provide technical background for survey personnel.

The survey was divided into Phases 1 and 2, with more than 600 architectural and engineering firms employed, using over 2000 graduates of shelter analysis courses. The basic function of the first phase was to identify and classify potential shelter as it currently existed. In Phase 2, qualified shelters were marked and stocked. In addition, feasibility and cost estimates both for adding ventilation to increase capacity and shielding to increase PF's were made.

III. PHASE 1

AE firms were asked in Phase 1 to inventory day and night population and potential fallout shelters in assigned geographical areas and to collect information on shielding which would be used by the National Bureau of Standards to calculate protection factors. Various survey methods were employed by the AE teams ranging from visual inspection only (windshield survey) to a search of office records, including building plans, and an exterior and interior examination of structures. Examples of data sources employed were: Bureau of the Census publications, Sanborn maps, building codes, tax records, and zoning codes.

Approximately five million buildings with potential shelter space were covered by the survey. Excluding single-family residences, a facility was eligible to be surveyed if it were thought to have a PF of at least 20 (capable of reducing radiation intensity inside the shelter to one-twentieth of that outside) and potential space for 50 or more people. The AE firms recorded data on building parts, stories, setbacks, and basements, giving component dimensions and other structural information for each potential facility on separate FOSDIC forms (Film Optical Sensing Device for Input to Computers). Over 500,000 FOSDIC forms were processed for nearly 375,000 buildings.

After being filled in by the architects and engineers, the FOSDIC forms were sent to the Bureau of the Census for microfilming. The microfilm data were then converted to electronic computer tapes and forwarded to the National Bureau of Standards.

NBS used the data on building geometry and shielding to compute PF's and to estimate the number of people that could be sheltered. Results were made available

in Phase 1 PF listings which identify each shelter area by category according to shielding capability as indicated in Table I.

TABLE I

<u>Shelter Categories</u>		
<u>Protection Factor Category</u>	<u>Protection Factor Range</u>	<u>Reduction Factor Range</u>
1	20 - 39	.05 - .025
2	40 - 69	.025 - .0143
3	70 - 99	.0143 - .01
4	100 - 149	.01 - .0067
5	150 - 249	.0067 - .004
6	250 - 499	.004 - .002
7	500 - 1000	.002 - .001
8	over 1000	.001

A typical Phase 1 printout gives such information as standard location and facility numbers, names and addresses of facilities, and for each floor the contribution from walls and ceiling, the PF category (1-8), measurements of area and volume, and the number of people who could be sheltered on each floor. In the event that none of the floors in a given facility contained an area with a PF of at least 20, this fact was noted on the printout.

Figure 1 is an example of a specific facility description found in the Phase 1 printout for the Atlanta, Georgia, area. The top line gives the standard location (SL) number for identification purposes, the field office, and the contract number with the field office. This information is presented once at the beginning of each SL. The identification line includes such information as: a number designating the facility within the SL, the number of parts in the facility, the number of data

FIGURE 1

A Phase 1 Facility Printout

SL 3324-0004 FO-C4 C-03

FAC=00407 PT=01 cf 01 REV=0 ST=08 1330BLDG 1330 W PEACHTREE ST ATLANTA GA USE=51 OWN 4 PV=57 YEAR 1957 SM=6

STORY	A	B	C	D	CL	TOT	PF	FLOOR	S-AREA	CORE	VOLUME	PEOPLE
1	00	00	28	00	00	28	1	17820	8910		80190	891
2	00	00	38	00	00	39	1	17820	8910		98010	891
3	00	02	24	02	00	27	1	17820	8910			891
4	17	09	05	09	00	41	1	17820	8910			391
5	08	06	04	06	01	26	1	17820	8910			891
6	06	04	03	05	03	31	2	17820	8910			891
7	05	03	02	03	12	26	1	17820	8910			891

revisions, the number of stories in the building, the name and address of the building, a use class code, an ownership code, a physical vulnerability (PV) code (which describes the type of construction), the year of construction, and the survey method.

Of the eight floors in this building, seven were estimated to have a PF of at least 20. For each floor the ground contribution for each wall (A, B, C, D) and the ceiling (CL) or roof contribution are listed and totaled (TOT). A decimal and a first zero were omitted from the printout. In this instance the first story had a reduction factor (total contribution) of .028. Since the protection factor is simply the reciprocal of the reduction factor, the PF is slightly less than 36 (35.7) and falls in PF Category 1 (20-39).

The heading FLOOR is the total floor area in square feet using exterior wall dimensions. The S-AREA, or shelter area, is that fraction of the total floor area having a specified PF somewhat less than the center PF (for example, a floor having a center PF in PF Category 5 is assumed to have a PF of 100 in at least 70 percent of the total area). The CORE is that central area, if existing, which is surrounded on two or more sides by interior partitions and which may be considered the desired shelter area if it is smaller than the S-AREA. In this specific case no CORE information was reported.

The figure under the heading VOLUME is the floor area multiplied by story height, while PEOPLE (shelter capacity) is the CORE, when given, or S-AREA divided by 10 square feet for the first and upper stories, or VOLUME divided by 500 cubic feet for basements.

The resulting data from computations by NBS are summarized on various levels: (1) standard location, (2) county and county area, (3) state, (4) regional, and (5) national.

IV. PHASE 2

Since the major function of Phase 1 was to identify and classify potential shelter, structural data collected during the first phase related to existing shielding but not to habitability or possible modification. Once shelters were tentatively identified, however, it was possible to go back and do a more thorough and complete analysis.

During Phase 2, AE firms were required to perform detailed building inspections and analyses to verify PF calculations of Phase 1 and to determine both the feasibility and the estimated cost of adding shielding to increase protection factors in shelters falling in Categories 2 and 3 (PF 40 through 99) and to improve ventilation to increase capacity. In many cases, shelters originally assigned a low PF rating were, when examined during Phase 2, upgraded one or more categories. One of several explanations for this was the influence of a sill height factor which was not applied in Phase 1. Shelters falling in Category 1 were not further evaluated in Phase 2. This category was included originally as a "safety factor" to reduce the danger of omitting potential shelter which had a PF of at least 40. Shelters determined to have a PF of 100 or better were eligible for marking and stocking. Local civil defense officials were later authorized to mark but not stock PF Category 2 and 3 shelters when sufficient PF Category 4 spaces were not available. From this, one can see the obvious importance of upgrading Categories 2 and 3.

As a part of Phase 2 operations, a survey was made of selected special facilities including subways, tunnels, caves, and mines. Special facilities, like regular structures, were to be marked if they met the established criteria for public fallout shelters.

Elements of structural data needed to supplement Phase 1 data in any future machine updating program were gathered and entered on the Phase 2 Data Collection Form (DCF). These data included information on size and location of areaways, interior partitions, and aperture sill heights.

V. LIMITATIONS OF THE NFSS

The primary purpose of the National Fallout Shelter Survey was to obtain the largest number of shelters in the quickest time at the least cost. These fund and time constraints led to the development of data collection and machine protection factor computational procedures which could be accomplished quickly and economically, but which would properly identify the best shelter space relative to other space. The PF computational procedure used was essentially that of the Guide for Architects and Engineers (Reference 3).

It is generally felt that the NFSS accomplished the purpose stated above; however, a number of limitations were present in both the data collection system and the machine program for PF calculations. A number of the elements of data which were not accounted for in Phase 1 were later collected in Phase 2 in order to define more accurately buildings when and if a recomputation of protection factors is deemed advisable. Some of the major limitations of the NFSS which invariably tend to make the machine computed PF conservative are:

1. Chart 3 of the Guide for Architects and Engineers, which was used in the NFSS Computer Program, combines contributions from direct (G_d), scattered (G_s), and skyshine (G_a) directional responses. For upper stories of buildings which cannot "see" part or all of the plane of contamination or the sky, a portion of the direct and skyshine radiation is not actually encountered. Detector locations below grade in basements are also not subject to direct radiation which is a part of the contribution figured for the exposed portion of the exterior walls.

2. Sill heights of apertures were not a part of the machine computational program. This caused the aperture to be considered as extending from floor to ceiling with an excessive amount of direct radiation accounted for in the area which is actually solid wall below the sill level. Sill heights (only one value per wall) were recorded in Phase 2 and are available for future use. Some buildings were manually re-evaluated by the AE in Phase 2 when the sill correction factor was thought to be sufficient to increase the shelter to a PF Category 4 or higher.
3. Apertures were counted to the nearest 10 percent and considered as uniformly spaced in the wall. No adjustment was possible for apertures appearing only at the extreme end of the wall.
4. Mass-thicknesses were rounded down to the nearest 10 psf. With the usual "mystery" concerning the exact construction of walls, floors, roofs, etc., this is a very good procedure. However, this procedure often leads to considerably under-estimated PF's. When minimum weights are assigned and a floor is determined to be 27 or 28 psf, it must be rounded down to 20 psf. This extra mass becomes extremely important in light of the data presented in Chapter 3 on Categorization. These indicate that 81 percent of the buildings in the sample analyzed have four or fewer stories and that 42 percent of all shelters receive 40 percent or more of their total contribution from the ceiling.

5. It was possible to enter only one weight for a given wall, floor or roof. Experience indicates that many buildings have wall weights between the apertures which are quite different from the wall above and below the aperture.
6. Interior partitions were sought out and recorded in Phase 1 only if known in advance to be of heavy construction (masonry load-bearing or fire-break).
7. The AE Guide method does not account for the variation in dose due to different shapes of building parts. NFSS calculations were made assuming all building parts to be square.
8. Areaways were counted in Phase 1 as the first contaminated plane, but only when they exceeded 50 percent of the length of the adjacent wall. Since planes of contamination widths can be marked only in 10 foot increments and most are not actually that wide, the contribution would be overestimated.
9. Only three planes of contamination could be reported for each wall, and they were considered to extend for the entire width of the adjacent wall. One building in the RTI sample of surveyed buildings required the use of 19 azimuthal sectors and a total of 49 planes to accurately define the contaminated areas.

Proposed modifications to the computer program that would improve the procedure of PF computations with results closer to the "true" PF and more correct ordering of buildings by PF are contained in Chapter 7. Obviously, the recommendations cannot correct for errors made in inputs and can utilize only data already collected.

REFERENCES

1. Office of Civil Defense. Highlights of the U. S. Civil Defense Program. Washington: Office of Civil Defense, Department of Defense, June 1963.
2. Office of Civil Defense. Design and Review of Structures for Protection From Fallout Gamma Radiation. (Engineering Manual). Rev. ed.; Washington: Office of Civil Defense, Department of Defense, 1 October 1961.
3. Office of Civil Defense. Guide for Architects and Engineers. Washington: Office of Civil Defense, Department of Defense, December 1961.

Chapter 3

Categorization*

I. INTRODUCTION

As a sub-task of OCD Project 1115A, Analysis of Survey Data, RTI was directed to "categorize the surveyed structures with respect to technical shielding characteristics . . ." A necessary prerequisite to such categorization is the determination of the relevant technical shielding characteristics of the actual buildings, as determined by their gross structural characteristics, in the NFSS population. Since the NFSS population size is large (over 300,000 buildings were surveyed), a statistical study of building characteristics measured during the NFSS would seem to be in order. The results of such a study should be of value to many persons interested in the civil defense effort from points of view other than shelter categorization. This study and the presentation of its results herein was undertaken with this in mind.

In general terms the approach to this statistical study was:

1. Select a large random sample of surveyed buildings from the National Fallout Shelter Survey (NFSS) Phase 1 M1 and M2 files, which are maintained at the National Bureau of Standards Computation Laboratory (References 1 and 2).
2. Perform statistical studies on detailed structural properties in an attempt to determine correlation between overall shelter and building structure and protection from fallout radiation. More specifically, the study involves preparation of statistical tabulations relating protection factor with the numbers of

* Data in this chapter and Appendices A - E were submitted to OCD as Research Memorandum RM 81-9 (Reference 3).

shelters and buildings falling within selected incremental ranges of certain properties such as story number, percent apertures, contaminated plane width, floor area, dose source, and others.

3. Perform all data processing and calculations on the National Bureau of Standards IBM 7090 computer.

II. DESCRIPTION OF AVAILABLE DATA

The source of NFSS data is the FOSDIC forms (Figure 2) on which structural data were entered for the facilities (buildings) by architect - engineer contractors (Reference 4). These data were transferred to magnetic tape and then edited at the National Bureau of Standards (References 1 and 2).

After editing, protection factor (PF) results were calculated for each story of each building part (see Reference 4 for definition of building part) using essentially the method described as the "simplified approximate method" in Reference 5.

The complete edited Phase 1 FOSDIC data are available on nine reels of magnetic tape at the Computer Laboratory, National Bureau of Standards, Washington, D. C. These nine reels of tape are designated as the M1 file. The protection factor computation results for every shelter having a protection factor in Category 1 or greater, along with certain other relevant data, are available at the same location on four reels of magnetic tape designated as the M2 file. Complete and detailed descriptions of these data files are presented in References 1 and 2. Each FOSDIC schedule in the M1 file and each shelter entry in the M2 file is identified by a number consisting of twenty decimal digits representing, from left to right: standard location (eight digits), field office (two digits) contract code (two digits), facility number (five digits), part number (two digits), and revision number (one digit). The standard location contains both the OCDM and census codes which specify a geographical location. The field office and contract codes identify the responsible Architect - Engineering firm; the facility number identifies the building; the part number identifies the building part; and the revision number identifies the edit edition of the FOSDIC. On both files, the entries are arranged in order of increasing magnitude of this twenty digit number.

FIGURE 2

[illegible]

(continued)

FOSDIC Form

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III. SAMPLING TECHNIQUE

A. Methodology

In order that statistics representative of characteristics of complete buildings be readily available from the sample, it is necessary to use the building as the sample population unit rather than building parts or shelters, which serve as units in the M1 and M2 files, respectively. Furthermore, since the NFSS was originally biased against selection of buildings which would likely not contain satisfactory shelter space, it is deemed proper to exclude from the sample any buildings encountered in the files which are found to have no shelters rated at PF Category 1 or above. This latter condition results in the requirement that the sample be drawn from the M2 file which contains the calculated PF results. The M1 file contains only the input data to the PF calculation program, including data for many buildings which would be not acceptable in the sample.

File entries for all shelters in PF Category 1 or above for each facility to be included in the sample are extracted from the M2 file by incremental selection. By this is meant that for a predetermined integral increment N , every N th qualified building is selected starting with the n th facility, where n is a randomly chosen integer such that $0 < n \leq N$, and proceeding throughout the file. A building qualifies to be included in the tally if it contains at least one shelter in PF Category 1 or above. In addition to being a straightforward and simply executed selection procedure, this method provides the added bonus of yielding a sample stratified on geographical location. A sample stratified on geographical location is proportioned in population by geographic location in essentially the same ratios as the total universe. This is a consequence of the ordering of facilities in the files on, primarily, their standard locations.

After the selection of buildings and accumulation of shelter data from the M2 file, the M1 file is scanned, and the FOSDIC data for all parts of the sample buildings are merged with the shelter data and written on a sample tape to be used as input to the statistical study calculations.

B. Detailed Sampling Procedure

The sample selection was done in two stages, each involving an independent computer run. It was followed by a third independent run for the purpose of printing out data for the selected facilities.

Step 1. BSSM2, Building Sample Selector from NBS M2 Tapes (Shelter File)

a. Random Number Generation

A self-seeding arithmetic random number generator designed to generate floating point random numbers in the interval zero-to-one (written for the IBM 7090 computer by Mr. F. C. Radford of this Institute, see subroutine RNDM, Appendix B) is used. The random number is multiplied by the selection interval integer, N, and the product rounded up to the nearest integer, n. The selection interval integer, N, is input at running time (see Section III A).

b. Building Selection

The four M2 file tapes are searched by successively reading into core storage, records containing 300 shelter units of eight words each and then scanning through the record to select facilities. Starting with, and including the nth qualified building, every Nth qualified building

is selected for the sample. A building is defined as being qualified if it contains at least one shelter in PF Category 1 or higher.

Shelter files are identified as belonging or not belonging to the same facility by comparing the first seventeen characters of the twenty character identification key (see Section II above). Shelters belonging to the same facility are ordered successively on the file tapes. File entries for accepted shelters are transferred in essentially unaltered form to an intermediate binary sample tape.

Operating instructions are given in Appendix A and program listings are given in Appendix B.

Step 2. BSSM1, Building Sample Selector from NBS M1 Tapes (FOSDIC File)

In this step, shelter file entries for selected facilities are read from the intermediate sample tape prepared in Step 1 above, and the M1 file tapes are searched for the corresponding FOSDIC schedules. Merged M1 and M2 data then are written on a finished sample tape. The FOSDIC schedules are ordered in the M1 file on the same twenty character key as was used in ordering the M2 file entries. Thus, all FOSDIC schedules are found in one pass through the nine reels of tapes.

FOSDIC schedules are read from the M1 file tapes into core storage in blocks of 60 schedules, each schedule using 45 words of storage. The stored block is scanned to find all schedules for which the first seventeen characters of the identification key match those of the M2 file entries. All M1 and M2 file entries for the selected

facilities are written on the binary sample tape in essentially unaltered form. The only important differences in the form of the data on the M1 and M2 tapes and sample tape are:

- a. The M1 and M2 file entries are merged on the sample tape.
- b. The first two words of each of the eight-word M2 entries has been deleted. These same data are contained in the first two words of the M1 file entries for each building part.
- c. The data may be read from the sample tape by FORTRAN read tape statements.

During the course of these calculations, information necessary for complete identification of each FOSDIC schedule is written on the system output tape for off-line printing. This output contains, for each FOSDIC schedule, the eight-digit standard location designation, field office code, contract code, facility (building) number, part number, revision number, and the facility name and address, the latter as given in item 2 of the FOSDIC form (Figure 2).

Operating instructions are given in Appendix A and program listings in Appendix B.

Step 3. BSPO, Building Sample Printout Program Number One

Using the sample tape as input, two BCD tapes are prepared for off-line printing. One tape contains a printout of the M1 FOSDIC data and the other contains a printout of the M2 PF data. Figures 3 and 4 show typical printouts taken from the sample. The information content and formats in these printouts are identical to those described in Reference 2 for the NFSS results.

Operating instructions are given in Appendix A and program listings in Appendix B.

FIGURE 3

FOSDIC Data Output

(Sample)

(2) WISCONSIN TURNER BLDG 606 W WIS AVE MILWAUKEE													(1) PAGE NO. 11	PAGE	
													(3) 45510017		
(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)			
EA	07	01044	01	C	01	21	1929	43	51	4	1	1			
(17) AREA DIMENSIONS															
				SIDE A	SIDE B	(18) HEIGHTS									
				63	150	TOTAL							212		
				EXTERIOR WALLS	0								10		
				CORE 1ST STORY	0								BASEMENT		
				CORE UPPER STORY	0								1ST STORY		
				BASEMENT PERCENT	7	***							UPPER STORY		
													10		
(19) ROOF AND SETBACK HEIGHT															
				***	SIDE A	SIDE B	SIDE C	SIDE D							
				ROOF	0	0	0	0						SIDE D	
				SETBACK NO. 1	50	0	0	0						0	
				SETBACK NO. 2	C	C	C	C						0	
				SETBACK NO. 3	C	C	C	C						0	
(20) CONTAMINATED PLATES															
				PLANE 1	SIDE A	SIDE B	SIDE C	SIDE D						SIDE D	
				EFFECTIVE HEIGHT	0	40	40	40						-3	
				WIDTH OF PLANE	30	11	11	11						10	
				PLANE 2	5	50	120	70						70	
				EFFECTIVE HEIGHT	20	10	10	10						10	
				WIDTH OF PLANE	0	0	0	0						0	
				PLANE 3	0	0	0	0						0	
				EFFECTIVE HEIGHT	0	0	0	0						0	
				WIDTH OF PLANE	0	0	0	0						0	
(21) SURVEY METHOD CODE 7															
(22) FLOOR AND ROOF DESCRIPTION															
				BASEMENT	6	1ST FLOOR	6	UPPER FLOORS	6	ROOF	6				
(23) STRUCTURE DETAIL															
				BASEMENT	SIDE A	SIDE B	SIDE C	SIDE D							
				EXTERIOR WALLS	15	30	15	15						SIDE D	
				HGT ABOVE GRADE	0	3	6	3						15	
				APERTURES	0	0	0	0						3	
				INTERIOR WALLS	0	0	0	0						0	
				1ST STORY	9	18	9	9						0	
				EXTERIOR WALLS	0	0	0	0						60	
				APERTURES	30	0	20	20						0	
				INTERIOR WALLS	0	0	0	0						0	
				UPPER	9	18	9	9						0	
				EXTERIOR WALLS	0	0	0	0						30	
				APERTURES	30	0	20	20						0	
				INTERIOR WALLS	0	0	0	0						0	
(24) UPPER AFTER CONSTRUCTION CHANGE															
				NO CHANGE	X	X	X	X						X	
				STORY NUMBER	0	5	0	0						0	
				EXTERIOR WALLS	0	0	0	0						0	
				APERTURES	0	30	0	0						0	
				INTERIOR WALLS	0	0	0	0						0	

SL=4551-0017 FO=EA C=07 FAC=C1044

PT=01	OF 01	REV=0	ST=21	WISCONSIN	TOWNSHIP	BLDG	606	%	WTS	AVE	MILWAUKEE	FLOOR	S-AREA	CORE	VOLUME	PEOPLE
STORY	A	B	C	D	CL	TOT	PF									
-1	0	0	0	0	0	0	0	0	0	0	0	0	6610	0	0	66100
0	0	0	0	1	1	1	2	7				6610	6610	0	0	66100
2	12	0	7	9	0	29	1					3450	4725	0	0	47250
3	8	0	6	2	22	2						9450	4725	0	0	47250
4	6	0	5	10	25	1						9450	4725	0	0	47250
7	2	0	32	1								4410	2205	0	0	22050
6	13	6	16	0	41	1						4410	2205	0	0	22050
9	5	11	6	12	0	33	1					4410	2205	0	0	22050
10	5	8	6	10	0	29	1					4410	2205	0	0	22050
11	5	6	5	8	0	24	2					4410	2205	0	0	22050
12	4	6	5	6	0	21	2					4410	2205	0	0	22050
13	4	5	7	5	0	22	2					4410	2205	0	0	22050
14	4	5	5	5	0	19	2					4410	2205	0	0	22050
15	4	5	5	5	0	18	2					4410	2205	0	0	22050
16	4	5	4	5	0	17	2					4410	2205	0	0	22050
17	4	5	4	5	0	16	2					4410	2205	0	0	22050
18	3	4	3	4	1	16	2					4410	2205	0	0	22050
19	3	4	3	4	3	17	2					4410	2205	0	0	22050
20	3	4	3	4	12	25	1					4410	2205	0	0	22050

FIGURE 4

PF Data Output
(Sample)

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IV. STATISTICS OF STRUCTURAL CHARACTERISTICS

A. Methodology

All buildings in the sample are classed by PF according to the criteria discussed below. Buildings and shelters contained within them then are placed in sub-classes according to structural characteristics as described in the sections to follow. Finally, tallies of shelters and buildings for the sub-classes are output in tabular form along with appropriate means and standard deviations.

1. Building PF Class

For the purpose of this study, all buildings in the sample are classed and grouped by class according to the PF of the highest rated shelter in the building. Thus, a building in PF Class 1 would have at least one shelter rated at PF Category 1, but none rated higher. A building in PF Class 2 would have at least one shelter rated at PF Category 2 but none higher, etc.

2. Shelter Statistics

Statistics on shelter characteristics are collected from the sample (see Appendices C and D for details of the computer program) and output in numerical tabulations along with complete FOSDIC and PF data (these latter are output in the same formats as illustrated in Figures 3 and 4) separately for each of the eight building PF classes. Specific structural characteristics studied are:

- | | |
|-----------------------------|------------------------------|
| a. story number | e. interior partitions |
| b. percent apertures | f. wall mass thicknesses |
| c. contaminated plane width | g. dose source |
| d. floor area | h. percent basement exposure |

For each of these tabulations the number of shelters falling in the sub-classes defined by these characteristics are listed for each PF category. Additional details are given in Section IV. B.

Similar tabulations are prepared from shelter statistics accumulated for all building PF classes.

3. Building Statistics

Tabulations similar to those for shelters are presented for buildings where the numbers of buildings are listed for each structural property by PF category. The PF category for a building is the same as its building PF class (see Section IV. A. 1). Specific structural properties studied are:

- | | |
|------------------------|--|
| a. story number | e. wall mass thickness |
| b. percent apertures | f. physical vulnerability
(PV code) |
| c. interior partitions | g. number of building parts |
| d. floor area | |

Additional details are given in the following sections.

B. Details of Data Classification

1. Factors Affecting the Whole Sample

- a. The sample population is restricted to buildings containing at least one shelter in PF Category 1 or greater.
- b. Shelter statistics are accumulated only for shelters rated at PF Category 1 or higher.
- c. Shelter statistics do not include sub-basement shelters.
- d. Building statistics do not include buildings having only sub-basement shelters, even though such buildings may be included in the sample.

- e. Building statistics are intended to be representative of the building as a whole; and consequently, averaging over the whole building frequently is required.
- f. The accumulation of statistics does not take into account any relevant effects caused by subdivision of buildings into multiple parts.

2. Description of Individual Tabulations

Appendix E contains summaries for all shelters and buildings in PF Classes 1 - 8 categorized by the following structural characteristics:

a. Shelter Statistics

(1) Story Number

Each shelter is classed according to PF category and story number, ranging from 0 (for basements) to a maximum of 45. The story number for each shelter is taken from the M2 file entries.

(2) Percent Apertures

Percent apertures, averaged over the four walls, are calculated for all shelters. Each shelter is classed according to PF category and percent apertures, the latter at intervals of 10 percent. Percent apertures are determined from FOSDIC entries 23i-23l for basements, entries 23u-23x for first stories, or entries 23g-23j or 23w-23z for upper stories (see Figure 2).

(3) Contaminated Plane Width

Sums of contaminated plane widths for unshielded planes below the shelter floor level are averaged over all four

sides for first and upper story shelters. Each shelter is classed by PF category and plane width, the latter in 30-foot intervals out to a maximum of 3000 feet. The shelter floor height is determined for each side from FOSDIC entries 23e-23h, 18c, and 18d. Contaminated plane widths and heights are determined from FOSDIC entries 20a-20x.

Starting with the closest plane on side A, plane widths are accumulated for each plane in succession outward which is below or level with the shelter floor, until a plane higher than the floor level is found, or until the widths of all three planes have been accumulated. Summation then skips to the next side. The final sum is divided by four.

(4) Floor Area

Floor areas of all shelters are calculated as the product of FOSDIC entries 17a and 17b. Each shelter is classed by PF and the logarithm (base 10) of the floor area in increments of one in log (area), ranging from 2 to 7. Shelters with area greater than 10^6 square feet are not found in the sample.

(5) Interior Partitions

Each shelter is classed by PF if one or more nonzero quantities are found in FOSDIC entries 23m-23p for basements, 23y-23b for first stories, 23k-23n, or 23a-23d for upper stories, as the case may be.

(6) Wall Mass Thickness

Average wall mass thicknesses are calculated for each shelter by summing the PSF entries for all exterior and

interior walls and dividing by four. Each shelter is classed according to PF and average PSF, the latter in 25-pound increments, out to a maximum of 500 PSF. All values greater than 500 PSF are included in the 475-500 PSF classes.

FOSDIC entries 23a-23d and 23m-23p are summed for basements, entries 23q-23t and 23y-23b are summed for first stories, and entries 23c-23f and 23k-23n or 23s-23v and 23a-23d are summed for upper stories, as the case may be.

(7) Dose Source

For each shelter, the fraction of total radiation dose for each wall contribution and the ceiling contribution are calculated from the M2 file data. Then each shelter is classed by PF category and dose source class. There are five dose source classes numbered 1 through 5, defined as follows:

Class 1. No single contribution is as large as 40 percent of the total.

Class 2. One wall contributes 40 percent or more, but no other contribution is as large as 40 percent.

Class 3. Two walls each contribute 40 percent or more.

Class 4. Ceiling contributes 40 percent or more, but no other contribution is as large as 40 percent.

Class 5. One wall and the ceiling both contribute
40 percent or more.

(8) Percent Basement Exposure

Each basement shelter is classed by PF and by the
average percent of exposure above grade of its walls. The
exposure classes are in increments of 10 percent.

The exposure fraction is calculated as the sum of
FOSDIC entries 23e, 23f, 23g, and 23h divided by four
times FOSDIC entry 18b.

b. Building Statistics

(1) Story Number

Each building is classed by building PF class and
story number. The story number is the number of stories
in the building as taken from FOSDIC item 10. If there
is more than one building part, the largest value of
FOSDIC item 10 for the several parts is used.

(2) Percent Apertures

Buildings are classed by building PF class and by
average percent apertures, the latter in increments of
10 percent. Percent apertures are averaged over all
stories and all four walls for all parts. FOSDIC entries
23i-23l are used for the basement, entries 23u-23x for
the first story, entries 23g-23j for upper stories below
construction change, and entries 23w-23z for upper
stories at and above construction change.

(3) Interior Partitions

Buildings are listed according to their building PF classes if they are found to contain interior partitions. A building is considered to contain an interior partition if a nonzero quantity is found in any one or more of the FOSDIC entries 23m-23p, 23y-23b, 23k-23n, or 23a-23d.

(4) Floor Area

The floor area for each building part is calculated as the product of FOSDIC entries 17a and 17b, and the sum over all parts is taken for each building. Each building is classed by building PF class and by the logarithm (base 10) of the total floor area as described in Section IV. B. 2. a. (4) above.

(5) Wall Mass Thickness

Buildings are classed by building PF class and by average wall mass thickness, the latter in 25 PSF increments, to a maximum of 500 PSF. Average wall mass thicknesses in excess of 500 PSF are included in the 475-500 PSF classes.

Wall mass thicknesses are summed over all four walls including both exterior and interior walls, and all stories for all building parts. The final sum is divided by four times the total number of stories for all parts. FOSDIC entries 23a-23d and 23m-23p are used for basements, entries 23q-23t and 23y-23b for first stories, items

23c̄-23f̄ and 23k̄-23n̄ for upper stories below construction change, and items 23s̄-23v̄ and 23ā-23d̄ for upper stories above construction change.

(6) Physical Vulnerability

Each building is classed according to building PF class and PV code as they are defined in References 2 and 4. The PV codes are taken from FOSDIC entry 12. When there is more than one building part, the numerically largest PV code is used.

(7) Number of Building Parts

Each building is classed by building PF class and by number of building parts. A maximum of twenty parts may be accommodated.

3. Calculation of Means and Standard Deviations

For each specific shelter and building characteristic listed in a tabulation, the mean PF category and the standard deviation is calculated. These are listed in the right hand two columns of each tabulation. Similarly, for each PF category the mean shelter or building characteristic and the standard deviation are calculated. These are listed in the bottom two rows in each tabulation.

Some shelter and building characteristics have a continuous distribution of values. For these, mid-increment values were used in calculating means and standard deviations. For characteristics with discrete distributions, including PF category, discrete values as listed in the tabulations were used. Characteristics with discrete distributions are:

- a. PF category
- b. story number
- c. dose source

Means and standard deviations for grouped data are calculated as follows:

If the data are grouped so that for the value x_i of the independent variable for the i th group, there are n_i data, then define:

$$S(x) = \sum n_i x_i \quad (1)$$

and

$$S(x^2) = \sum n_i x_i^2 \quad (2)$$

If N is the total number of data, \bar{x} is the mean value of the independent variable, and $\sigma(x)$ is the standard deviation of x , then

$$N = \sum n_i \quad (3)$$

$$\bar{x} = S(x)/N \quad (4)$$

$$\sigma(x)^2 = \left[S(x^2) - [S(x)]^2/N \right] / (N-1) \quad (5)$$

V. SAMPLE CHARACTERISTICS

The overall statistical characteristics of the sample and its parent population are as listed below.

1. Building selection increment = 200
2. Random number generated = 4
3. Total number of shelters on M2 file = 1,042,027
4. Total number of shelters scanned = 1,041,900 (The shelters not scanned were on the final short record of the last file tape.)
5. Total number of buildings scanned = 308,130
6. Total number of buildings rejected (Buildings containing no shelters rated in PF Category 1 or higher were rejected.) = 73,646
7. Total number of buildings in the sample = 1541
8. Total number of FOSDIC schedules (building parts) in the sample = 2091
9. Total number of shelters in the sample = 4421
10. Total number of buildings contributing to tabulation statistics = 1539^{*}
11. Total number of shelters contributing to tabulation statistics = 4336^{**}
12. Total number of sub-basement shelters = 34

Table II presents the overall PF distribution of shelters and buildings in the sample.

* Buildings containing only sub-basement shelter space were not included in the statistics.

** Shelters in PF Category 0 (no shelter in PF Category 1 or better) and sub-basement shelters were not included in the statistics.

TABLE II

Sample PF Distributions of Shelters and Buildings

<u>Shelter Statistics*</u>		
<u>PF Category</u>	<u>Number</u>	<u>Fraction</u>
0**	51**	.0115
1	1830	.4139
2	992	.2244
3	402	.0909
4	322	.0728
5	278	.0629
6	214	.0484
7	98	.0222
8	234	.0529
<u>Building Statistics</u>		
<u>PF Class</u>	<u>Number</u>	<u>Fraction</u>
1	483	.3138
2	361	.2346
3	150	.0975
4	142	.0923
5	110	.0715
6	104	.0676
7	57	.0370
8	132	.0858

* These shelter statistics may be compared with the column totals in the story number tabulations of Section IX of Appendix E to determine the PF categories of the sub-basement shelters which otherwise are not included in the statistics.

** Shelters in PF Category 0 (PF less than 20) are automatically excluded from the sample except in cases where a part of an acceptable building contains no usable shelter. The FOSDIC schedule and one shelter entry for the part are included in the M1 and M2 files.

VI. DISCUSSION

No attempt will be made in this report to present an exhaustive analysis of the data presented herein. Indeed, the interpretations and implied cross correlations to be found in the data are numerous and will vary in importance depending upon the point of view of the individual. Accordingly, only the more apparent highlights will be pointed out and discussed briefly.

1. Story Number

At the lower PF categories the shelter tabulations show clearly a trend toward higher story number as the building PF class increases. On the other hand, in the tabulation for the total shelter population, the mode story number is zero for every PF category. Thirty-nine percent of the shelters are basements.

For buildings, the mean story number varies from three to four for all PF classes except PF Class 8, where it jumps to six. The paucity of tall buildings in the sample appears to be a very significant, and perhaps surprising result, and bears heavily on the statistics of major dose contribution discussed below.

2. Percent Apertures

As with story number, there is a trend toward higher percent apertures at lower shelter PF categories. However, neither the means nor the modes ever exceed 25 percent for shelters.

For the shelter totals, roughly the same comments apply, except that the means are slightly lower.

Means for buildings range from 17 to 19 percent with modes near this same range for all categories. There are ten buildings in the sample with 50 percent or more apertures.

3. Contaminated Plane Width

Results obtained from these tabulations are extremely interesting and dramatically point out the predominance of narrow limited planes of contamination. Though the maximum possible total width is 2970 feet, the widest average found is 1170 feet. For PF Category 1, the numbers of shelters are few with planes beyond 500 feet; and for higher categories the number of shelters become few at progressively lower widths until at Category 8, most are below 60 feet. Thus, the mean total width of dose-contributing contaminated planes is quite low. In the shelter totals the mode is less than 60 feet for every category.

4. Floor Area

The vast majority of shelters fall in the 10^3 - 10^4 square feet class for all categories. From the shelter totals it is seen that 78 percent of the shelters fall in this class. Similar results are found for buildings. There are no buildings or shelters with a floor area of 10^6 square feet or larger.

5. Interior Partitions

Most interesting here are the percentages of the NFSS shelters reported to have interior partitions. These range from 13 percent to 30 percent for the building PF classes. Seventeen percent of the total shelter population is found to have interior partitions. It is to be remembered that partitions were recorded in Phase 1 only if they were load-bearing or fire-break.

6. Wall Mass Thickness

There are no means in the 0 - 25 PSF range and only five in the 25 - 50 PSF range. In virtually every case, the mode is either 100 or 150 PSF. There is an unexpectedly high total of 44 shelters in the 475+ PSF classes. When tables such as those presented in References 4 and 6 are consulted, it is surprising to note the relatively small amount of material used in building exterior walls. For example, 100 PSF would correspond to approximately 12 inches of brick or 8 inches of reinforced concrete. The shelter totals show that the means range from 147 to 235 PSF. For buildings the means are lower but are still quite high.

7. Dose Source

The dose source tabulations clearly show large contributions from the ceilings. When such features as the low mean building story numbers, low mean sums of contaminated plane widths, and very high mean wall weights are considered, this result becomes more understandable. An effective area for application of additional shielding in order to increase effectiveness of shelters is indicated by these data.

8. Physical Vulnerability

The majority of buildings are concentrated under PV codes 32, 35, 36, 43, and 57. These are defined as follows (see Reference 2):

<u>PV Code</u>	<u>Description</u>
32	wall-bearing single story commercial or industrial buildings
35	wall-bearing 3-5 story buildings
36	wall-bearing 6-8 story buildings
43	steel-framed multi-story conventional buildings
57	reinforced concrete frame multi-story conventional commercial buildings

There were 30 tunnels or earth-covered structures in the sample.

9. Percent Basement Exposure

These results are as expected with the higher PF shelter having the least exposure. The average exposure for all basements is 22 percent. Only 185 of the total of 1691 basements were exposed 50 percent or more.

10. Number of Building Parts

Eighty percent of the sample building population have only one part, 12 percent have only two parts, and 4 percent have only three. One building has fourteen parts.

VII. RECOMMENDATIONS FOR FURTHER WORK

This work was intended to provide an introduction to statistical study of correlation between building structure and PF using the NFSS results. As such it is merely a pilot effort and is far from comprehensive. The results presented here suggest clearly that similar but more extensive studies are called for.

Of particular interest would be the determination of actual three-way correlations between PF, dose source, and various structural characteristics such as those studied here. Similar statistical studies on a shelter space basis also would be of interest. Correlations which point out regional characteristics would be of value. Depending upon the point of view and interests of the individual, there is virtually an unlimited number of interesting correlations which could be obtained.

The sample of 1541 buildings used for this study is still available on magnetic tape. Other similar samples, of any desired size, may easily be obtained using the same program decks. Variation in the sampling procedures could easily be effected by using the subprograms created for this work as a core around which the new sampling programs could be written. In summary, it is felt that sufficient spadework has been done to render feasible continued work in this area.

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Chapter 4

Analysis of NFSS Findings

I. INTRODUCTION

A major task of OCD Project 1115A was to "review the National Fallout Shelter Survey findings as they become available to estimate probable error, or reliability in light of existing experimental data and theoretical considerations." The Research Triangle Institute proposed to carry out this work by surveying a probability sample of buildings employing, with exacting care, a modification of the procedures used in the NFSS and a more refined PF computational procedure incorporating the method outlined in the Engineering Manual (Reference 1). Inferences could be drawn about the NFSS findings from this probability sample.

The primary objective of this survey of sample buildings from the National Fallout Shelter Survey (NFSS) was to determine what change in protection factor (PF) would occur if procedures more sophisticated than those used in the NBS-NFSS Computer Program (References 2 and 3) were adopted. Emphasis was placed on using as much as possible of the existing data collected by the AE firms in Phases 1 and 2 of the NFSS. However, in order to calculate a PF using the Engineering Manual method, certain additional elements of data needed to be obtained, while other data needed to be measured and recorded more accurately.

Using data collected by RTI, a Phase 1 FOSDIC form was prepared for each sample building and submitted to NBS for processing using the NBS-NFSS Computer Program. Comparison of results from the RTI FOSDIC with the Engineering Manual

computations would then indicate changes in protection factors due to procedural differences.

A secondary objective of the survey was to determine the accuracy of the input data of the NFSS. This was necessary to determine the true procedural differences and to estimate the reliability of future calculations using existing data. Input differences were estimated by comparing NFSS Phase 1 FOSDIC inputs and printout results with NBS-NFSS computations using data submitted by RTI on FOSDIC forms.

II. SAMPLE SELECTION

The universe to be surveyed by a sampling procedure consisted of all buildings in the 40 largest cities in the United States having at least one shelter rated at PF Category 2, 3, or 4 in Phase 1 of the NFSS. These PF categories were selected for analysis because changes in these categories would be of most importance to the overall shelter situation. PF's were generally expected to have been underestimated in Phase 1 because of use of the conservative procedures of the AE Guide.

The 40 largest cities in the United States contain approximately 60 percent of all shelters in PF Categories 2, 3, and 4 and are all readily accessible by commercial air transportation. Moreover, all geographic areas of the country are represented; each civil defense region contains two or more of these cities within its boundaries.

The time element involved in conducting the field work and data analysis necessarily restricted the size of the sample. It was estimated that this time factor would make it possible to survey between 30 and 60 buildings.

An analysis was made of the significance with which the differences between the NBS-NFSS Computer Program and the Engineering Manual could be estimated. Based on the results of this analysis, a sample of 30 buildings was considered adequate for detecting differences in estimated PF ratings of 10 units.

The size of the sample was set at 33 buildings by a systematic sub-sample of every other building in an initial sample of 60 with a random starting point chosen in each region. Buildings from civil defense regions containing only one sample building in the sample of 60 were included automatically in the sub-sample of 33 buildings. A listing of the sample buildings is contained in Table III.

Details of the selection of sample buildings to be surveyed by RTI and an estimate of the statistical confidence are presented in Appendix F.

TABLE III

33-Building Sample Surveyed by RTI

	<u>OGD Region</u>	<u>City</u>	<u>Standard Location</u>	<u>Facility Number</u>	<u>Address</u>
1	1	Boston, Mass.	1315-0026	03130	30-32 North Bennet Street
2		Newark, N.J.	1541-0066	00984	73-77 Seventeenth Avenue
3		Bronx, N.Y.C.	1641-0046	00923	650 Grand Concourse
4		Bronx, N.Y.C.	1641-0138	03782	1235 Grand Concourse
5		Bronx, N.Y.C.	1641-0194	01907	81 West 182nd Street
6		Brooklyn, N.Y.C.	1642-0207	03232	5101-23 13th Avenue
7		Brooklyn, N.Y.C.	1642-0495	04335	485 Bedford Avenue
8		Manhattan, N.Y.C.	1644-0028	01072	304 Broadway
9		Manhattan, N.Y.C.	1644-0063	02527	435 Hudson Street
10		Manhattan, N.Y.C.	1644-0096	02947	300 Park Avenue
11		Manhattan, N.Y.C.	1644-0126	00858	362 W. 52nd Street
12		Manhattan, N.Y.C.	1644-0156	01917	327 W. 75th Street
13		Manhattan, N.Y.C.	1644-0204	03371	47-49 W. 129th Street
14		Manhattan, N.Y.C.	1644-0260	01773	360 Cabrini Boulevard
15		Queens, N.Y.C.	1645-0017	00764	4107 10th Street
16		Queens, N.Y.C.	1645-0538	07616	14415 Sanford Avenue
17		Rochester, N.Y.	1651-0005	00598	37-49 South Avenue
18	2	Washington, D.C.	2211-0005	00511	2700 Connecticut Avenue
19		Washington, D.C.	2211-0062	03448	18th and C Streets
20		Louisville, Ky.	2351-0029	01973	1011 W. Market Street
21		Cleveland, Ohio	2541-0058	01272	917 Euclid Avenue
22		Philadelphia, Pa.	2675-0017	01738	257 S. 16th Street
23	3	Memphis, Tenn.	3731-0043	01301	70 West E.H. Crump Blvd.
24	4	Chicago, Ill.	4121-0065	02101	3456 N. Damen Avenue
25		Chicago, Ill.	4121-0144	03302	320 N. Clark Avenue
26		Chicago, Ill.	4121-0490	06068	111 W. Jackson Blvd.
27		Chicago, Ill.	4121-0868	06023	10875-81 S. Racine Ave.
28		Indianapolis, Ind.	4241-0013	01003	604 E. 38th Street
29	5	Houston, Texas	5581-0026	06118	619 Main Street
30	6	St. Louis, Mo.	6434-0122	01971	1010 Pine Street
31	7	Los Angeles, Calif.	7231-0453	01427	403 West 8th Street
32		San Francisco, Calif.	7274-0072	05214	650 5th Street
33	8	Seattle, Wash.	8521-0061	01462	1215 4th Avenue

III. FIELD SURVEY PROCEDURES

A. Planning

The planning of the field work portion of this survey was done at the same time the sample was being designed. It was determined that in order to calculate a PF using the Engineering Manual method, certain additional elements of data needed to be obtained while others needed to be measured and recorded more accurately. The sensitivity of changes in PF's resulting from changes in mass thicknesses of roofs, walls, and partitions was analyzed early in this project in order to help identify structural data requiring more precision in evaluation. Results of this analysis are contained in Appendix G.

Elements of data required to supplement Phase 1 and 2 data were:

1. Mass thicknesses (psf) of walls, partitions, floors, and the roof to the nearest pound using minimum material weights for each type of material.
2. More exact location and size of apertures and indication of their distribution; i.e., uniformly distributed or predominantly at one end of the building.
3. Sill heights of apertures for each sill (not always uniform).
4. Mass thicknesses (psf) and location of all interior partitions.
5. Variations in mass thicknesses of roofs, floors, and exterior walls; for example, walls above and below apertures are often different from the sections beside the apertures.
6. Sizes and locations of all areaways.
7. Location and size of partial basements since the basement was reported in Phase 1 only as a percentage of the first floor area.
8. All planes of contamination because only three sides were reported for each building side on the FOSDIC form.

To facilitate proper collection of data on the dimensions and construction of the sample buildings, a data collection form was developed. The form was completely filled out in the field for all buildings on which building plans were not available. On those buildings for which plans were available, the form was used primarily to enter details of the construction which had to be confirmed in the field. A sample of this form is included as TAB 1 of Appendix H.

A letter was sent to the local civil defense office in each of the cities containing sample buildings to inform them of the impending visit of the RTI survey team. Their assistance was requested in obtaining copies of the Phase 1 FOSDIC form and Phase 2 Data Collection Forms and building plans for each of the sample buildings.

B. Sanborn Maps*

Sanborn Map sheets covering the area indicated to be at least 300 feet out in radius from the exterior walls of all the sample buildings were ordered from the Sanborn Map Company, Pelham, New York, in early November, 1962. Most of the data necessary to define planes of contamination around the sample buildings could be extracted from these sheets. Through visual inspection of the area surrounding the sample buildings, the various data on the Sanborn Maps were verified to rather close limits.

The overall accuracy of the maps as determined by visual inspections proved to be excellent. Even very recent changes in the areas under review brought about by demolition and/or construction were generally indicated by Sanborn. Those connected with the survey feel that using the maps saved a tremendous amount of effort in the field.

* These maps give a bird's-eye view of city blocks and include heights of buildings and other construction details.

C. Visits to Local CD Offices and AE's

Upon arrival in each city containing the sample buildings, the survey team first visited the local CD office.

The field survey team made very few contacts with the AE firms who surveyed the sample buildings. Most of the time, these contacts were to obtain copies of Phase 1 FOSDIC's in their possession.

Initially, it was felt by members of the RTI survey team that the AE firms could be of considerable assistance in supplying the team with notes and other incidental data on the sample buildings. However, after a few calls were made, it was decided that not enough valuable data were being received from the AE's to warrant investment of the time to call on them.

D. Procurement of Plans

After visiting the local CD office, the team generally went in search of detailed building plans for the sample buildings. This search entailed visiting either the building owner or superintendent, the architect who drew the plans, or the city building inspector's office. All of these proved to be quite fruitful. Of the 33 buildings surveyed, architectural drawings (either original or renovation) were available on 28; detailed layout sketches were obtained on two; and no plans of any sort were available for three buildings. Of the latter three, two were very old buildings on which all plans had been lost by the owners, and none were available from secondary sources. Entry was denied by the manager in the case of the third building; the owner could not be contacted, and plans were not available elsewhere.

The city building inspector's offices were by far the best source of plans. If plans were on file, they could be reviewed, and only pertinent sheets then had to be taken out to be reproduced. Also, it was found that the work of

physically inspecting the buildings went much more easily with plans already in hand. In a number of cities, the building inspector's office files did not date back far enough to include buildings in the sample. Nevertheless, plans were either obtained or reviewed at this source in about a half-dozen of the sample cities. In New York City, plans or sketches were obtained from the Department of Buildings for all fourteen of the sample buildings.

E. On-Site Inspection

Before leaving each city, RTI personnel visited every sample building and inspected it thoroughly. Numerous photographs were taken from all sides of each building, primarily to get a record of grade elevations of the planes of contamination.

Permission to enter was requested from the manager or superintendent. Only in one instance was this denied. If the team did not already have the building plans in hand, permission was also requested of the authority contacted to review and reproduce certain sheets. The building authorities were always quite willing to allow the team this privilege if plans were available.

While RTI personnel were at the building location, the Sanborn Map data were verified, and various data on the building plans were also checked against the actual construction. Notes were made of any discrepancies between plans and construction.

For the buildings on which architectural plans were not available, additional dimensional and structural detail measurements were made during this visit. Needless to say, inspection of these buildings took much longer than those for which plans were available.

F. Recommendations and Conclusions Concerning Data Collection

From experience gained in conducting the field work of this survey, the Research Triangle Institute recommends that in any future updating program of the NFSS, an extensive effort should be made to obtain detailed architectural plans on every building surveyed; without plans, those doing the data collection work enter into a guessing game in determining almost every structural detail they encounter. Each of the sample buildings was quite different; each had its own "individuality." It can also be stated that there is no such thing as a "typical building," because of the special conditions associated with each one.

IV. COMPUTATIONAL PROCEDURES

A. Determination of Input Information

The first step in the computation of a building PF by the Engineering Manual method was to analyze the structural characteristics of the building and the location of the contaminated planes. This analysis led to the identification on Sanborn Maps of azimuthal sectors which closely approximate the actual planes of contamination which would affect that part of the building. In many cases the number of sectors exceeded a dozen and for one building there were nineteen sectors and 49 planes. An example of a Sanborn Map with azimuthal sectors and planes of contamination identified is given in Figure 5. These azimuthal sectors were then drawn on the detailed building floor plan as indicated in Figure 6. The next step was to assign various interior partition, exterior wall, and floor weights, dimensions of apertures, etc., to these sectors and compute the wall crossing point for the limits of the planes of contamination (i.e., the amount of vertical wall "seen" by a plane). Sub-division of azimuthal sectors was often required to account for variations in psf of exterior walls or partitions, or for variation of aperture dimensions and sill heights within the sector. These dimensions, weights, etc., were obtained from building plans, Sanborn Maps, and visual inspection. For buildings without detailed plans available, all structural data were entered on a data collection form as contained in TAB 1 of Appendix H.

B. Computational Forms for Ground Contribution

When the analysis of the structural characteristics of the building and its associated contaminated planes was complete, this information was entered on computational forms developed to allow details of the computation to be made by personnel not necessarily familiar with the Engineering Manual.* These forms

* Voluminous data such as building plans, Sanborn Maps, data collection forms, input data calculations, computational forms, etc., required to define the building structural characteristics and make the Engineering Manual computations are not included as a part of this report but are retained on file at RTI.

FIGURE 5

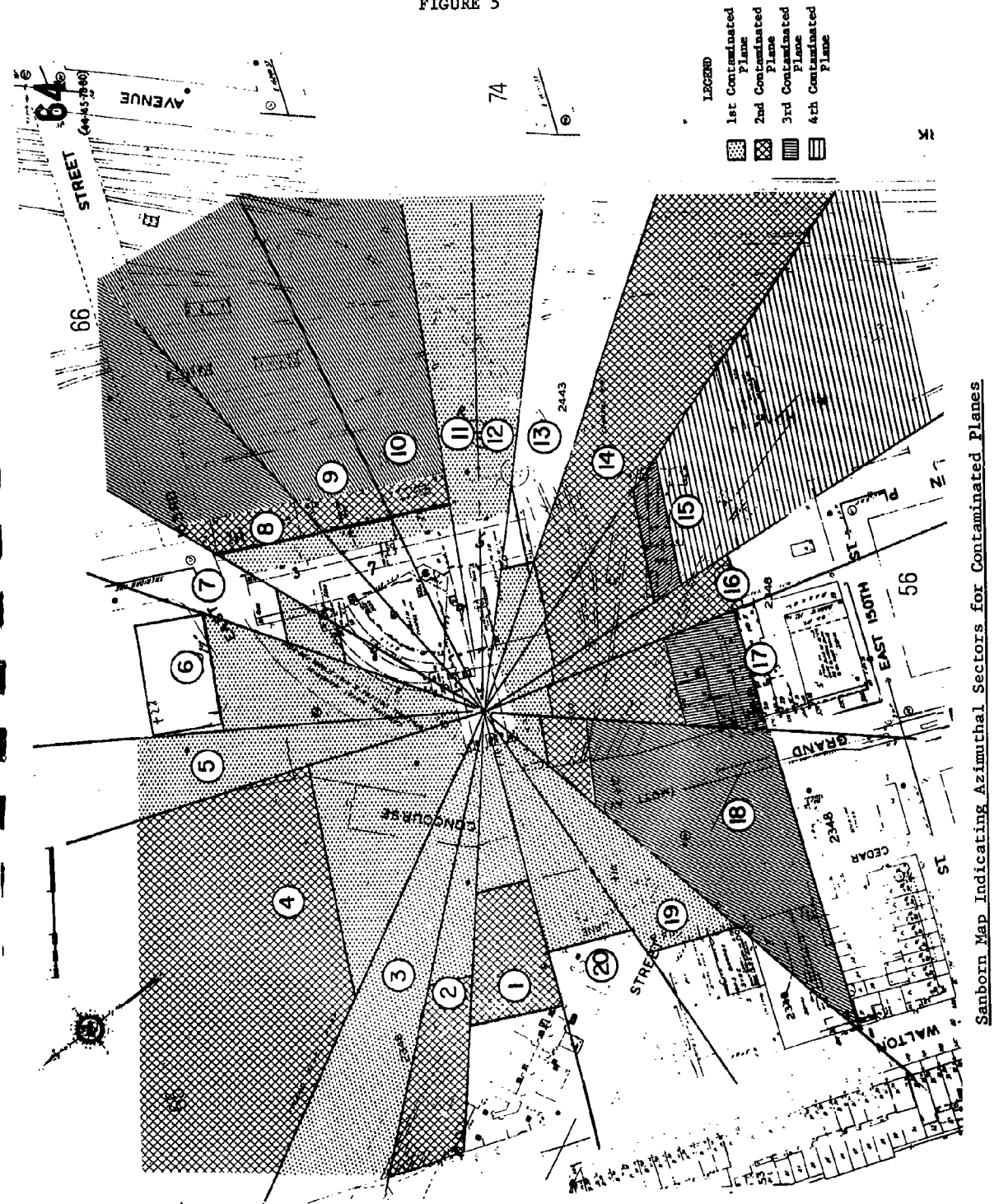


FIGURE 6



sometimes required entries, other than numbers, such as codes designating whether the detector level is between, below, or above the apertures, and whether the contaminated plane exposes the entire wall to fallout radiation. After these entries were made on the forms, a set of instructions indicating the special computational steps needed was consulted and the form was completed to yield the reduction factor.

The use of the forms differs slightly when the detector is above or below grade, and several types of forms are needed for a complete analysis.

1. Above Ground Computation

When the detector is located above the ground, three forms were used to calculate the total ground contribution (reduction factor). These three forms are: (1) Adjacent (contribution through the walls and apertures of the story containing the detector); (2) Through Ceiling (contribution through the walls and apertures of the story above the detector story); and (3) Through Floor (contribution through the walls and apertures of the story below the detector story). A detailed description of these forms, the instructions for their use, and the functional equations from which they were developed are given in Appendix H. A brief description is as follows:

a. Adjacent Form (Figure H-1 of Appendix H)

The contributions as computed through the use of this form represent the following cases:

- (1) Direct Contribution Through the Wall and Apertures
- (2) Scatter Contribution Through the Wall and Apertures
- (3) Skyshine Contribution Through the Wall and Apertures

b. Through Ceiling Form (Figure H-3 of Appendix H)

The Through Ceiling Form is similar to the Adjacent Form except that no direct radiation is encountered.

c. Through Floor Form (Figure H-4 of Appendix H)

The Through Floor Form is used to calculate the direct and scattered contributions from the story below the detector story.

2. Computational Form for Basement Contribution (Figure H-5 of Appendix H)

If the basement has an areaway or some other plane lower than the detector, the contributions from each sector involved are computed using the Adjacent Form to account for direct radiation.

For unexposed basements, the Through Ceiling Form is used to compute the contribution from the second story and a Basement Form (modification of the Through Ceiling Form) is used for the contribution from the first story.

If the basement is partially exposed, the Through Ceiling Form is used for the first story contribution and a modified Basement Form is used for the exposed portion of the basement.

C. Roof Contribution

The roof contribution was calculated by standard Engineering Manual methods (References 1 and 4). The functional equations for a building with interior partitions are:

$$C_o(\omega'_u, X_o) + [C_o(\omega_u, X_o) - C_o(\omega'_u, X_o)] B'_1(X_1)$$

where $C_o(\omega'_u, X_o)$ is the contribution inside the core as defined by interior partitions of weight X_1 , and $C_o(\omega_u, X_o)$ is the total roof contribution including the core. Contributions were differenced for peripheral roof areas.

D. Total Contribution and Protection Factors

The sum of the contributions from the ground contribution forms required for a building and the contributions from the roof gave the total reduction factor (RF). The reciprocal of this number ($1/RF$) gave the protection factor (PF) for the point in the part of the building evaluated.

V. ANALYSIS OF FINDINGS

A. Input Data Analysis

The structural data collected by RTI for the sample of 33 buildings are contained in Section I. B. c. of Appendix I. The data collected by RTI (RTI FOSDIC) and submitted on FOSDIC forms to NBS for calculation are compared with data collected by the AE's in Phase 1 (AE FOSDIC). Estimated average differences (\bar{d}) and standard errors of the average differences ($s_{\bar{d}}$) for selected building characteristics are contained in Table IV. The formulas used in determining the average differences and standard errors of the average differences are contained in Section II of Appendix I.

The estimated average differences appearing in Table IV as plus values indicate that the AE made estimates higher than RTI for a number of structural details. The large number of elements of data in this category were very surprising because it was felt that the AE would tend to underestimate the input data, in accordance with instructions. The large difference noted for interior partition psf is attributed to Phase 1 instructions (Reference 5) requiring only load-bearing and fire-break partitions to be considered.

B. Computations Analysis

Contributions and PF's determined by the AE's and by RTI for a specific detector location in each sample building are presented in Section I. B. d. of Appendix I. Results are given for NFSS Phases 1 and 2 and for RTI submitted Phase 1 FOSDIC forms as well as the Engineering Manual computations. A comparison of each of these PF's normalized relative to the Engineering Manual PF is made for each of the sample buildings in Figure 7. A statistical analysis of these data is presented in Table V. The formulas used in determining the average differences and standard errors of the average difference are contained in Section II of Appendix I.

TABLE IV

Estimated Average Input Differences for
Selected Building Characteristics
 (32 Buildings)^{1/}

<u>STRUCTURAL CHARACTERISTICS</u>	<u>AVERAGE DIFFERENCE (AE-RTI)</u>	<u>STANDARD DEVIATION OF AVERAGE DIFFERENCE (Sample)</u>
(1) Total Height of Building (feet)	+0.32	1.22
(2) Length of Exterior Wall (feet) (per side)	+4.94	3.07
(3) Basement Exposure (feet) (per side)	+0.41	0.58
(4) Roof psf	+9.09	6.52
(5) First Floor psf	+14.66*	8.00
(6) Upper Floor psf	+0.70	7.04
(7) Basement Wall psf (X_e) (per side)	+52.78 *	29.73
(8) First Floor Wall psf (X_e) (per side)	+16.62	13.79
(9) Upper Floor Wall psf (X_e) (per side)	+21.33*	11.65
(10) Basement Partition psf (X_1) (per side)	-13.76**	6.23
(11) First Floor Partition psf (X_1) (per side)	-13.65*	6.90
(12) Upper Floor Partition psf (X_1) (per side)	-11.92*	5.79
(13) Basement Percent Apertures (per side)	+0.17	1.19
(14) First Floor Per Cent Apertures (per side)	+8.68**	2.78
(15) Upper Floor Per Cent Apertures (per side)	+8.93**	3.77

* Significant at the 10 per cent level with 13 degrees of freedom.

**Significant at the 5 per cent level with 13 degrees of freedom.

^{1/} Access denied in one of 33 sample buildings.

Statistical procedures are contained in Section II of Appendix I.

TABLE V

Estimated Protection Factor AverageDifferences for the RTISample of 32 Buildings ^{5/}

	<u>AVERAGE DIFFERENCE</u>	<u>STANDARD DEVIATION OF AVERAGE DIFFERENCE</u>
AE - RTI (No X_1) ^{1/}	+21.94*	11.90
AE - RTI (X_1) ^{2/}	+10.55	13.77
RTI(X_1) - EM ^{3/}	-109.56**	37.69
AE - EM ^{4/}	-99.01**	44.10

NOTES:

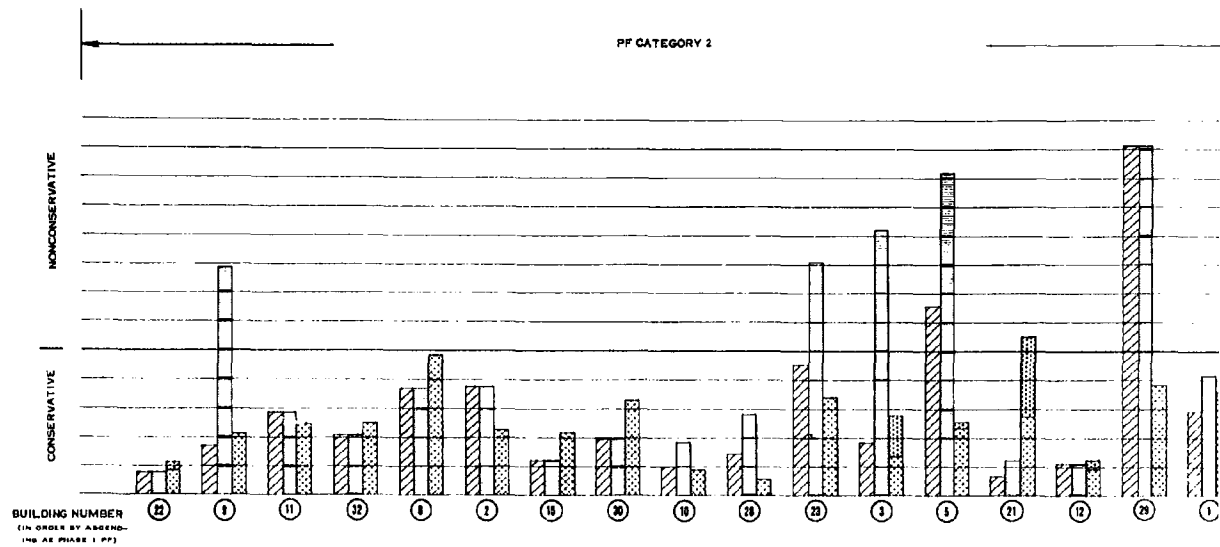
^{1/} AE Phase 1 FOSDIC Results minus RTI FOSDIC (without partitions) Results^{2/} AE Phase 1 FOSDIC Results minus RTI FOSDIC (with partitions) Results^{3/} RTI FOSDIC (with partitions) Results minus RTI Engineering Manual Results^{4/} AE Phase 1 FOSDIC Results minus RTI Engineering Manual Results^{5/} Access denied in one of 33 sample buildings.

* Significant at the 10 percent level with 13 degrees of freedom.

** Significant at the 5 percent level with 13 degrees of freedom.

FIGURE

Comparison of 33 Sam

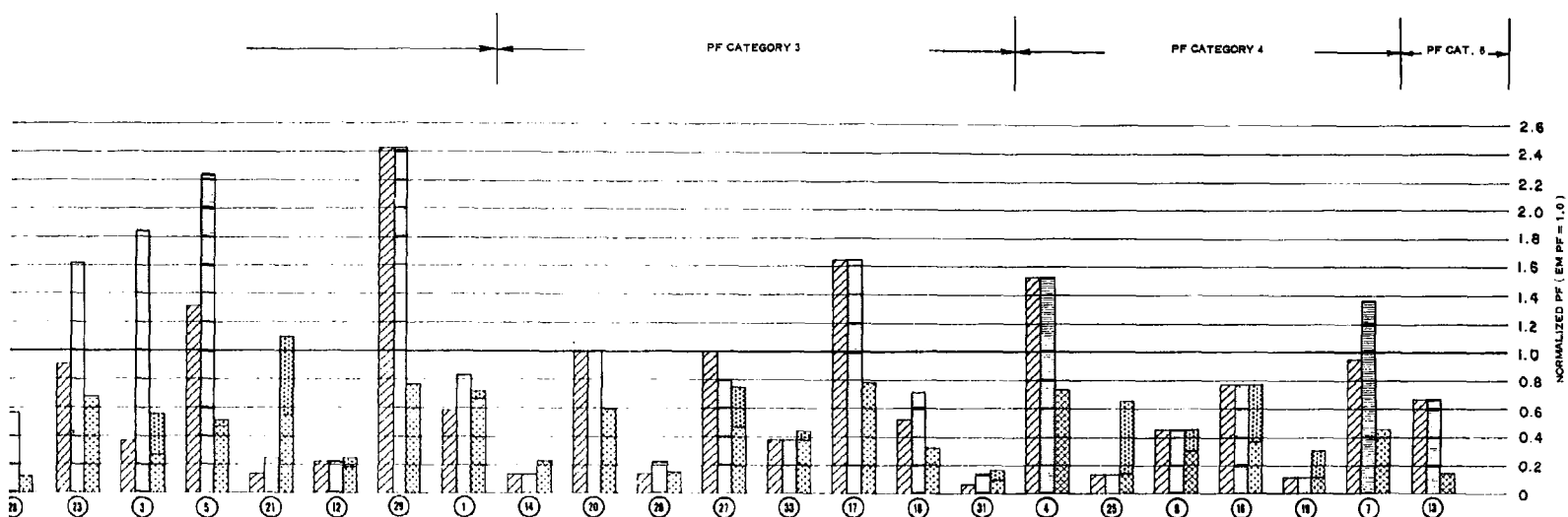


1

BUILDING NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ENGINEERING MANUAL PF	116	69	164	66	45	65	147	278	125	275	73	292	179	558
AE PHASE 1 PF	67	50	59	100	59	48	140	125	42	53	42	63	250	71
AE PHASE 2 PF	96	50	300	100	100	48	200	125	196	100	42	63	250	71
RTI FOSDIC (WITHOUT PARTITIONS) PF	77	31	43	45	21	63	67	83	53	48	36	53	53	111
RTI FOSDIC (WITH PARTITIONS) PF	83	-	91	-	23	-	-	125	-	-	-	71	-	125

FIGURE 7

Comparison of 33 Sample Building PF's*



1	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
164	64	45	65	147	278	125	275	71	292	379	556	212	161	47	194	1080	71	455	250	62	—	770	550	71	185	26	127	1250	100	189
59	100	59	48	140	125	42	53	42	63	250	71	50	125	77	77	125	71	59	30	56	—	100	71	71	53	63	50	77	42	71
100	100	100	48	200	125	196	100	42	63	250	71	50	125	77	120	125	71	110	40	100	—	100	120	56	104	63	50	170	42	71
43	45	21	63	67	83	53	48	36	53	53	110	91	59	37	—	125	42	250	43	42	—	110	83	33	20	20	83	110	50	71
91	—	23	—	—	125	—	—	—	71	—	125	—	125	37	53	330	—	500	58	—	—	500	—	53	20	—	—	200	—	83

2

The first set of data presented in Table V for "AE - RTI (No X_1)" compares NBS-NFSS Computer Program results using NFSS Phase 1 FOSDICS prepared by AE's with computer results using FOSDICS prepared by RTI without allowances for interior partitions (except load-bearing and fire-break walls). This comparison of results indicates the data input differences for each building, since the RTI submitted FOSDIC was prepared in accordance with NFSS Phase 1 instructions. The fact that the average difference of PF's is +22, which indicates that the AE results were 22 units higher (nonconservative) than those using the RTI FOSDIC, is surprising since it was originally felt that the AE data inputs would be quite conservative.

The second set of data in Table V for "AE - RTI (X_1)" is a comparison of the AE Phase 1 results with the optimum computer results, since all interior partitions were counted by RTI. It can be seen that adding partitions decreased the difference between PF's from +22 units without partitions to +11 units, which was no longer statistically significant.

An indication of procedural differences between the NBS-NFSS Computer Program and the Engineering Manual is given in the Table V "RTI(X_1)-EM" results. This indicates that the NBS-NFSS Computer Program PF results are conservative by an average difference of 110 units per building. This is substantial justification for modifying the Computer Program as recommended in Chapter 7 to make it more like the Engineering Manual method.

The overall survey differences, which account for both input and procedural differences, are shown in Table V "AE - EM" results. These results, which show a difference of -99 units, indicate that the NFSS data are conservative by an average of 99 PF units.

It should be pointed out that the conservative bias and substantial random errors in the NFSS findings are of great significance in many applications of NFSS

data. This is particularly true of vulnerability analyses and related areas (need for additional shelter or shelter modifications, speed of radiological recovery, need for decontamination, etc.).

C. Reasons for Differences in Computational Results

The major reason for discrepancies between AE Phase 1 results and RTI Engineering Manual results is due to computational procedure differences. Many of the sample buildings were in downtown areas where limited planes of contamination are encountered. Present computer program procedures do not properly account for the mutual shielding effect of these surrounding buildings in estimating direct and skyshine directional responses. Aperture sill height corrections not made in Phase 1 would have considerably reduced contributions for most of the buildings in the sample.

A number of obvious differences were also noted in the Phase 1 input data for the sample buildings. Three buildings, for example, actually have fewer than the number of reported stories. This makes quite an underestimate of roof contribution because of the weight of the extra reported floor. Another building had the contaminated planes for building sides A and B mis-matched, which caused an underestimated contribution since the worst contamination was placed on the shortest side of the building (Building 12). One unusual case was the occurrence of a river improperly reported as a contaminated plane adjacent to the building (Building 25). Over- and under-estimated dimensions, weights, and percentages of apertures were also frequently encountered.

An analysis of all factors, both procedural and input, felt to have influenced the difference in PF between the NFSS Phase 1 computer method and the Engineering Manual method is contained in Section I. B. e. of Appendix I for each of the sample buildings.

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Chapter 5

Comparison of Experimental and Calculated Protection Factors

I. INTRODUCTION

Although attenuation of gamma rays is quite well described by various theories, all of the problems for which solutions can be readily obtained require rather simple geometries and often necessitate approximations of the true case. The OCD publications Shelter Design and Analysis, Volume I (Reference 1) and the Design and Review of Structures for Protection From Fallout Gamma Radiation (Engineering Manual) (Reference 2), which are an outgrowth of Dr. L. V. Spencer's NBS Monograph 42 (Reference 3), are an attempt to systematize the analysis of a building's protection factor (PF). This chapter compares the protection calculated by RTI using the Engineering Manual method with that determined experimentally by Edgerton, Germeshausen and Grier, Inc. (References 4 and 5).

Real buildings are generally very complicated and require a rather complex analysis. Although building construction plans are usually available, equipment location and plan modifications are very difficult to determine. However, these unknowns may greatly affect the protection factor. Also, in many cases the construction plans specify only minimum thicknesses for certain items such as floor and roof slabs, resulting in underestimated PF's.

The only way to measure the protection factor at a point in a building is to measure the dose at this point when the building is exposed to an infinite fallout field of known intensity. Since this is impractical, various techniques have been devised to simulate a fallout field. The radiation emitted by the simulant must approximate the spectrum of a fairly early fallout field (approximately 1 hour), must remain uniform in spectrum and intensity over a reasonable period of time, and must

be suitable for spreading over a large area. The requirement for radiation spectrum is very closely approximated by cobalt-60 (generally within 10 percent - see Reference 6); however, spreading highly radioactive material over a large area presents extremely complex problems to the experimenter. The problem of spreading radioactive material has been partially circumvented by the use of the "pumped source" technique. The "pumped source" technique uses water pressure to push a radioactive source uniformly through thin tubing, and when the tubing is spread uniformly over an area, the time integrated effect is a close approximation to an area source. This pumped source technique has been used by various organizations with very good results (see Chapter 6, Research Review).

The accuracy of the Engineering Manual method of computing PF's could be measured by comparing results of an experiment with a detailed Engineering Manual computation for the same building and its simulated limited planes of contamination. Because construction plans generally specify only minimum thicknesses and do not show internal equipment, the Engineering Manual computation is expected to be conservative when compared with experimental results if internal contents are ignored. RTI has calculated theoretical partial reduction factors * for four buildings for which radiation dose contributions have been determined experimentally by Edgerton, Germshausen and Grier, Inc. (EG & G). If the contaminated planes experimentally evaluated were the only contributing areas, the building PF would, as usual, be the reciprocal of the total reduction factor ($\frac{1}{RF}$). The experimental results, which are reported in References 4 and 5 as dose contributions, are normalized in this chapter to be numerically equal to partial reduction factors. ** The buildings compared are:

* Partial reduction factors are numbers that represent the dose rate received in the building from the limited plane of contamination divided by the dose rate 3 feet above an infinite field of contamination with the same source density.

** The actual dose rate given in the reports was divided by the infinite free-field cobalt-60 dose rate of 500 mr/hr/mc/sq ft. (see p. 40, Reference 6).

1. Brookhaven National Laboratories Medical Research Building (Reference 4).
2. The Laboratory of Nuclear Medicine and Radiation Biology of the University of California in Los Angeles (Reference 5).
3. The Communications Center of the Los Angeles Police Department Building (Reference 5).
4. A classroom structure at North Hollywood High School (Reference 5).

These buildings varied from medium to heavy construction and from very light-weight partitions to heavy multi-partition complexes. Part of the ground contributions and all of the roof contributions were measured experimentally in cases where they were thought to be significant.

Engineering Manual calculations for the Brookhaven building were made using data from detailed building plans without an on-site inspection. A field survey of the remaining three buildings was conducted, during which detailed building plans were also obtained. Considerable data, such as details of the experiments, some building plans, and photographs, were obtained from Mr. Zolin Burson of EG&G.

II. RESULTS AND COMPARISONS

Results of comparisons between Engineering Manual calculations and experimental results are discussed in Sub-sections A through D below.

A. Brookhaven National Laboratories (BNL) Medical Research Building

The BNL Medical Research Building is a large, one-story, reinforced concrete and brick building with an exposed basement, medium weight floor and roof, and a very large number of significant partitions. Structural details appear in Appendix J.

1. Experimental Results

The pumped source technique was used to measure contributions for ground contamination extending to 108 feet from the north and east sides of the building, and for entire roof contamination. The tubing on the ground was spaced about every 6 feet with the two sides measured one at a time. The roof contamination was simulated by spacing the tubing every 4 feet over the entire roof. The point chosen for analysis by RTI was position 98, located approximately in the center of the basement and four feet above the floor. Experimental dose rates converted by RTI to partial reduction factors for this point (Reference 4) are:

Ground: North Side	= 0.000052
East Side	= 0.000440
Roof:	= 0.001720
Total:	= 0.002212

2. Theoretical Calculation

The basement has approximately 400 12-inch-square concrete columns spread throughout on approximately 10 foot centers. The exposure of

the basement varied from 2 feet to 11 feet. The combination of basement exposure, columns, windows, and doors necessitated the drawing of 22 azimuthal sectors radially from the detector location in order to perform the Engineering Manual calculation.

The roof contribution was split into five "fictitious" buildings because of first floor partitions and 8-inch-square concrete cross beams in the basement ceiling.

The results of the theoretically computed partial reduction factors for position 98 are:

Ground: North Side	= 0.000227
East Side	= 0.000773
Roof:	= <u>0.003170</u>
Total:	= 0.004170

3. Comparison of Results

The comparisons between experiment and calculation for this building show calculated to experimental ratios of 4.3 and 1.75 for the north and south ground contributions, respectively, and 1.84 for the roof contribution. The difference between the east side factors as calculated and experimentally measured is equivalent to the attenuation afforded by a 20 psf interior partition. The results from the north side are not quite so close; however, since only the upper few feet of the basement wall were exposed, the majority of the contribution must have penetrated the numerous pipes, beams, and equipment shown in the basement photographs of Reference 4. The difference in contributions is equivalent to attenuation provided by 60 psf material. The correlation between experiment and calculation was also complicated by the fact that the ground sloped along the building and also sloped away from the building in most directions - particularly in the northerly direction.

The difference between the computed and experimental roof factors can be resolved by only a 20 percent increase in the floor and roof mass thicknesses.

B. The Laboratory of Nuclear Medicine and Radiation Biology at UCLA

The Laboratory of Nuclear Medicine is a two-story, reinforced concrete building with an exposed basement, very heavy roof and floor slabs, and a number of lightweight partitions. Structural details appear in Appendix J.

1. Experimental Results

The pumped source technique, with a 6-foot tube spacing, was used to measure ground contribution extending from the exterior wall to 72 feet in the front and 60 feet in the rear of the building. The pumped source was also used to measure the contribution from the two areaways that would receive fallout contamination. Since the roof and floor slabs were very heavy (112 psf each), no roof contribution was measured. The point chosen for analysis was a central position, Number 34, located three feet above the basement floor. The experimental partial reduction factors obtained for the various runs are:

Large Areaway	= 0.00016
Small Areaway	= 0
Front Exposure	= 0.00036
Rear Exposure	= 0.00024
Total	= 0.00076

2. Theoretical Calculations

It was necessary to divide the areaway and ground contamination into eight azimuthal sectors in order to make Engineering Manual calculations for position 34. The mass thickness of the partitions in each sector varied from 20 psf to almost 100 psf. The partial reduction factors computed for the limited planes are:

Large Areaway	= 0.000260 with 100 psf equipment (0.000466 without)
Small Areaway	= 0.000009
Front Exposure	= 0.000878
Rear Exposure	= 0.000380
Total	= 0.001527

3. Comparison of Results

The experiment and the detailed calculation of the contributions from the rear areaway differ drastically when such items as heavy equipment and their concrete bases are not taken into account. The 100 psf mass thickness for the equipment is figured as a minimum and brings the experiment and the calculation to within a factor of two.

The contributions from the exposed portion of the basement wall are close when an analysis is made of interior contents through which radiation must pass. Affecting the front contribution are numerous storage racks, some filled with sand samples which could easily be equivalent to the 35 psf of material which accounts for the difference. From the rear, the radiation must penetrate the wall and one or two partitions whose weight, because of using minimum weights, could have easily been underestimated by the 15 psf needed to account for the difference in observed and calculated reduction factors. The major difference in ground contribution comes from the large areaway. This difference is probably due to using minimum weights in estimating a "plaster exterior wall" and in omitting desks and equipment in the building and storage drums in the areaway.

Since the geometry for the exposed portion of the basement is fairly simple, a comparison between the experiment and the NBS-NFSS Computer Program method (References 7 and 8) seemed useful. The NBS-NFSS Computer

Program yields a total ground contribution about 50 percent higher than the experimental results, even when the additional partition weights required to make the Engineering Manual calculations equivalent to experimental results are used.

C. The Communications Center of the L. A. Police Department

The Los Angeles Police Department is in an eight-story, reinforced concrete building; however, the first floor, where the communications center is located, extends beyond the rest of the building. Because the first floor extends beyond the main building, it would receive a peripheral roof contribution from the roof over this extended part. Structural details appear in Appendix J.

1. Experimental Results

The pumped source technique was used for both the ground and roof contributions. The ground contribution was measured from the first 36 feet of an adjacent parking lot on only one side of the communications center. A small concrete planting-box wall and a heavy reinforced concrete wall below aperture sill height reduced the ground contribution considerably. Since the shielding was great and a very large radiation source would have endangered nearby personnel, a low-range precision scintillator was required for radiation monitoring instead of the standard ionization chambers.

The roof near the communications center was in two levels; one part had a 6-inch reinforced concrete roof and the other had a light-weight (10 psf) metal roof. The measured partial reduction factors at position 3, located 3 feet above the first floor and at approximately the center of the communications center, are:

Ground:	=	0.00004
Roof:	=	<u>0.00022</u>
Total	=	0.00026

2. Theoretical Calculation

Because of the complexity of the interior partitions, the ground contamination was divided into nine azimuthal sectors with partition weights varying from 10 psf to 190 psf. There were also a number of 18-inch-square concrete columns.

Calculation of the roof contribution required four separate calculations; two as normal roof contributions and two as wall-scatter contributions. The partial reduction factors for the building are:

Ground:	=	0.000090
Roof:	=	<u>0.000272</u>
Total	=	0.000362

3. Comparison of Results

The calculated total contribution is within 30 percent of the experimental values. The ground contributions differ by a factor of two; however, considering the extremely small contributions and the fact that desks, equipment, etc., were not considered in the computation, this difference is not surprising. The difference of 24 percent between the roof contributions is reasonably close.

D. Classroom at North Hollywood High School

The classroom evaluated at North Hollywood High School is a two-story, reinforced concrete building with fairly lightweight floors and roof. Structural details appear in Appendix J.

1. Experimental Results

The pumped source technique was used for both ground and roof contributions. Six-foot tube spacing was used on the ground and 7-foot spacing

was used on the roof.

Because of the nearness of residential structures, only very limited planes of contamination could be measured. The ground contribution was measured on two sides, one out to 18 feet and the other out to 24 feet. The point chosen for comparison with the Engineering Manual was Number 17, located in the center of the building (in the corridor) and three feet above the first floor. The measured partial reduction factors are:

Ground: North Side	= 0.00180
East Side	= 0.00034
Roof:	= 0.00190
Total	= 0.00404

2. Theoretical Calculation

Because of the number of interior partitions, windows, and doors, eight azimuthal sectors were required to determine the ground contribution. The roof contribution was calculated by representing the building as three fictitious buildings. The results of these computations are:

Ground: North Side	= 0.00215
East Side	= 0.00047
Roof:	= 0.00500
Total	= 0.00762

3. Comparison of Results

Although the total computed contribution differs from the experimental value by almost a factor of two, it can be seen that the ground contributions from the two methods agree quite closely. In fact, considering uncertainties in experiments, computations, interior contents,

etc., the difference of 22 percent in ground contribution is reasonably close.

The difference in the roof contributions is equivalent to a 33 percent increase in the overhead mass thickness. Examination of the contribution from the core region of the roof shows that the calculated value is twice the total experimental value. One possible explanation for this discrepancy is that the thicknesses of floor and roof slabs indicated on the building plans are minimums and the actual thicknesses exceed the specified ones by 33 percent. Another reasonable explanation is that construction tile or some other material was inserted between the joists, but was not indicated on the construction plans obtained by RTI. If the overhead mass thicknesses necessary to make Engineering Manual calculations equal experimental results are inserted into the NBS-NFSS Computer Program, computed reduction factors are approximately 40 percent higher than the Engineering Manual result.

III. CONCLUSIONS

In general, the theoretical contributions are within a factor of two of the experimental values and always indicated conservative protection even though individual experimental contributions covered a very wide range (.000052 - .0017). It is felt that if an accurate estimate of interior contents were available and were used along with the known construction of the building, the agreement would be even closer. Section IV of Chapter 6 shows that the Engineering Manual method of calculating ground contribution for simple geometries adequately predicts (within 15 percent) the observed experimental results for infinite fields. No detailed experimental confirmations of the Engineering Manual predictions for limited plane data are available; therefore, one cannot completely rule out the possibility that part of the above discrepancy may be due to approximations in the theoretical computation. The results of this chapter support the recommendations made in Chapter 6 that limited strip data of Technical Operations Research be compared with Engineering Manual calculations. It is believed, however, that the largest deviation is caused by the inability to determine the effect of interior contents, pipes, cross beams, etc., and to know the exact mass thicknesses of irregular structures.

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Chapter 6

Research Review

I. INTRODUCTION

The importance of protection factor computations and their reliability has prompted several organizations to undertake theoretical and experimental investigations of structure shielding against fallout radiation. One of the major tasks of OCD Project 1115A was to "evaluate new information on shielding for application to the computation of protection factors for surveyed structures." The objectives of this task are several: (1) to determine whether existing methods for computing protection factors need modification to agree with new data; (2) to recommend new investigations in areas where gaps exist in current shielding knowledge; and (3) to suggest applications of new shielding information to problems confronting the Office of Civil Defense. The purpose of this chapter is to report the results and conclusions of RTI's study of the pertinent research activity in shielding.

Information for this study was obtained by site visitation, personal contact, and literature search. A review of bibliographies of shielding research indicated that the Technical Operations Research (Tech Ops) modeling experiments would provide an important test of protection factor predictions. Accordingly, RTI made an extensive examination of available data from Tech Ops and reported the implications of this research in Appendices L, M, and N. Other significant work includes that of Edgerton, Germeshausen, and Grier, Inc. (EG&G), who observed dose angular distributions in actual fallout fields from weapons tests and measured protection factors for several classes of structures. The detailed analysis and comparison of EG&G's measured PF's with RTI's Engineering Manual calculations for several buildings are discussed in Chapter 5.

Sections II and III of this chapter present a summary and general discussion of research by Tech Ops and EC&G. Section IV below discusses the various PF computational methods and compares their predictions for simple geometries with experimental results. Section V categorizes research reports by elementary absorber geometries. A summary of RTI's recommendations as determined in the research review is presented in Section VI. The detailed studies represent only those accomplished to date, and similar studies of other reports listed herein are continuing at RTI under a subsequent OCD research contract (OCD Sub-task 1115C).

II. TECHNICAL OPERATIONS RESEARCH EXPERIMENTS

A. Modeling Technique

The modeling approach to measurements of radiation attenuation in structures was introduced by Clarke, Batter, and Kaplan (Reference 1) of Tech Ops in the fall of 1958. In initial experiments, dose measurements were carried out on full-scale structures at the Nevada Test Site, and on 1:12 steel scale models of these structures at Burlington, Massachusetts. Fallout was simulated with a pumped source technique in which a cobalt-60 source was circulated through plastic tubing over the ground. These early results indicated that modeling could be a very useful and convenient method for obtaining data on radiation protection offered by full-scale buildings.

Under the sponsorship of the Office of Civil Defense, the Tech Ops - OCD Modeling Facility at Burlington, Massachusetts, was conceived and developed into a productive source of attenuation data. From this facility has emerged a series of reports in which dose measurements on basic structures are compared with theoretical predictions of the AE Guide (Reference 2) and Engineering Manual (Reference 3).

B. Ranch House and Two-Story Frame House Model Experiments

The object of the first experiments (Reference 4) was further verification of the modeling technique as an economical means of obtaining shielding data on full-scale structures. The simulated structures were a concrete ranch house and a two-story wood frame house for which full-scale data were available in reports by Auxier, Buchanan, Eisenhauer, and Menker (Reference 5) and Batter, Kaplan, and Clarke (Reference 6), respectively. Perfect scaling was not possible because scaling laws call for increasing densities of all materials (air, ground, walls), by the same factor that reduces linear dimensions. Nevertheless, the feasibility and

verification of the modeling technique for above-ground detector locations were demonstrated in these experiments. This initial work is also described by Batter and Clarke (Reference 7) in the US NRDL Shielding Symposium Proceedings.

C. Multi-story Building Model Experiments

The object of subsequent experiments at the modeling facility was confirmation of protection factor computations for simple structures based on the methods developed for the OCD National Fallout Survey. Batter, Starbird, and York (References 8 and 9) investigated the effect of limited planes of contamination on the dose rate in a multi-story windowless building. Starbird, Velletri, MacNeil, and Batter (References 10 and 11) studied the effect of interior partitions in the same structure. Batter and Velletri (Reference 12) measured the radiation reflected from ceilings. The major conclusions and recommendations reported by Tech Ops are contained in Appendix O, and the effect of these findings on PF computations is discussed in Section IV of this chapter.

Detailed discussions of the results of the experiments on the multi-story building are presented in Appendices L, M, and N, which are derived from RTI Research Memoranda (References 13, 14, and 15). A comparison by RTI of the ratio of observed to calculated protection factors for the model (with its actual dimensions) with the same ratio for the full-size structure showed that essentially no error was introduced by the scaling process for above ground detector location (see Section II.C. of Appendix L). It is, however, recommended in Appendix L that penetration data such as that presented in the charts in the Engineering Manual be developed for the radiation of cobalt-60 and attenuation characteristics of steel.

D. Full-scale Experiments

In addition to the work with models, Tech Ops has successfully used the pumped source method to measure protection factors for several full-scale buildings. These

include an office building (Reference 6), a simple structure with a basement (Reference 16), residential-type structures (Reference 1), a concrete block house (Reference 17), a British residence (Reference 18), an open hole, and an underground fallout shelter (Reference 1). In general, the experimental results were in good agreement with the Engineering Manual calculations for the ground contribution. Other full-scale experimental work by Tech Ops includes an investigation of radiation reflected into an underground shelter by a projecting air vent by Bordeur and Batter (Reference 19), and measurements of scattering at interfaces by Clarke and Batter (Reference 20), Batter (Reference 21), and Clarke (Reference 22).

E. Monte Carlo Calculations

Monte Carlo calculations have been performed by Raso on the reflection and transmission of scattered gamma radiations (References 23 and 24), and roof barrier factors in steel and concrete for cobalt-60 radiation (Reference 25). This work is not complete and has not been evaluated by RTI.

III. EDGERTON, GERMESHAUSEN, & GRIER, INC., EXPERIMENTS

A. Introduction

Under the sponsorship of Civil Effects Test Operations of the U. S. Atomic Energy Commission, EG&G has conducted a series of measurements of direct interest to the National Fallout Shelter Survey program. Work reported includes the following:

1. Protection factor measurements have been made for the following structures (observed ranges of PF's are indicated in brackets):
 - a. Brookhaven National Laboratory Medical Research Center by Borella, Burson, and Jacovitch (Reference 26), [200-400 in basement, 12-20 on first floor] .
 - b. Single story stucco frame house by Burson, Parry, and Borella (Reference 27), [2.8-4.4] .
 - c. Earth covered shelter by Burson and Borella (Reference 28) [2500-15,000] .
 - d. Laboratory of Nuclear Medicine and Radiation Biology at UCLA by Burson (Reference 29), [10-2000] .
 - e. Family fallout shelter by Burson (Reference 29) up to [10,000] .
 - f. Communications Section of the Los Angeles Police Department Building by Burson (Reference 29) [50-150] .
 - g. Classroom at North Hollywood High School by Burson (Reference 29) [10-20] .
2. Ground roughness effects on the energy and angular distribution of gamma radiation from fallout have been determined by Huddleston, Kinkaid, Burson, and Klinger (References 30 and 31).

B. Full-scale Building Experiments

EG&G made PF measurements for full-scale buildings with finite planes of contamination simulated with the pumped source technique developed by Technical Operations Research. The source anisotropy, due to self-shielding, and tubing attenuation were both considered to be negligible by EG&G. (A detailed evaluation of these effects in modeling experiments has been made by Tech Ops and reported in Reference 8.) The PF for the house, 1b in Paragraph III A above, was determined by taking the ratio of measured doses for a finite plane of contamination in the absence and presence of the structure. The other PF's were computed by taking the ratio of the theoretical, infinite, cleared-field dose rate for the actual source density (500 mr/hr for cobalt-60 with density 1 mc/sq ft) to the measured dose rate in the sheltered area. The former approach is a relative one and has the advantage of being less sensitive to corrections associated with source and tubing characteristics, absolute calibration of the source and detector, and estimates of the far field contribution to the dose rate. The accuracy of the latter approach depends directly on the absolute accuracy of estimation and/or measurement of the above-mentioned factors. The far field contribution beyond a 60.5 foot radius for the house (1b in Paragraph III A) and beyond 15 feet from the edge of the shelter (1c in Paragraph III A) was neglected for these structures, and was estimated from theoretical considerations for the other structures (1a, d, e, f, and g). In addition, the skyshine contribution was estimated and included in structures 1d, e, f, and g. Preliminary comparisons were made by EG&G of the experimental PF's with values obtained from the AE Guide and Engineering Manual for the UCLA building (1d). Some results are shown in Table VI for a basement location.

TABLE VI

Computed and Experimental PF's for a
Basement Location in the
UCLA Building

<u>Method</u>	<u>Remarks</u>	<u>PF</u>
AE Guide	Used mass thicknesses in architectural plans. Neglected mass of mechanical equipment.	80
Engineering Manual	Same as above	150
Engineering Manual	Included mass of mechanical equipment	420
Experimental Result		680

At another location the calculated PF was 720 and the measured PF was 1100. In general, it appears that the EG&G Engineering Manual calculation and measurements agree within a factor of two.

RTI has completed detailed Engineering Manual calculations for the Brookhaven, UCLA, police, and school buildings (1a, d, f, and g of Paragraph III, A) for comparison with EG&G's data. These results are reported in Chapter 5.

C. Ground Roughness Experiments

The ground roughness experiments (Reference 30) were conducted by EG&G at the Nevada Test Site with actual fallout fields on a dry lake bed, rough desert terrain, and a plowed field. Successful measurements were made of dose angular distributions and dose rate variation with height above the ground. Such measurements are exceedingly difficult to plan and execute in view of the uncertainties in predicting fallout patterns. The results indicate that as a first approximation, ground roughness shielding can be treated by considering the fallout to be buried beneath a layer

of soil in an infinite smooth plane. If this approximation holds, the dose angular distribution at a height h above a rough plane would be the same as the dose angular distribution at some specific height, $h + T$, above a smooth plane. Estimates of T are 30 feet, 40 feet, and 50 feet for the lake bed, plowed field, and rough desert terrain, respectively. The agreement between the shapes of these measured curves and the theoretical curves of Spencer (Reference 32) for the dose angular distributions from the lake bed is quite close; however, differences in shapes become significant as the degree of roughness increases. Calculated values for absolute dose rates were 30-40 percent greater than the measured values.

The choice of the aperture opening in the collimator used to measure angular distributions was a compromise between a wide opening for good counting statistics and a narrow opening for high angular resolution. Poor angular resolution will distort the observed angular distribution in such a way as to broaden, shift, and reduce the intensity of the peak just below the horizon. If not taken into account, this effect could lead to errors in estimates of T or in conclusions on the agreement of shapes. A rough estimate made at RTI shows that the dose angular distribution at 3 feet above an infinite smooth plane when observed with EG&G's collimator would appear to have the same shape as the theoretical curve at a height of 8-15 feet on the basis of location of the peak, $\cos \theta_m$, and its width at half-maximum intensity. The shape distortion due to resolution will not be as pronounced at greater heights (rougher terrains) because the shapes are smoother and less peaked. It appears that EG&G's comparisons are based on observed distributions rather than distributions corrected for collimator resolution.

IV. STATUS OF THEORETICAL PREDICTIONS OF EXPERIMENTAL RESULTS

A. Introduction

The most recent summary (Reference 33) of shielding is Spencer's and Hubbell's "Report on Current Knowledge of Shielding from Nuclear Explosions," (1962 revision) in which 369 references are presented. Other references are reported in the rather extensive bibliographies contained in References 34, 35, 36, and 37. The reports considered pertinent to this section are listed in Table VII. The following paragraphs discuss the more important PF computational methods.

B. Spencer's Monograph

The best available, although quite complex, method for calculating the protection factor of a structure is that presented in Spencer's Monograph (Reference 32). The predictions of dose rates from contaminated flat roofs were experimentally confirmed by Schmoke and Rexroad (Reference 38). Later measurements with cobalt-60 sources surrounding a concrete block house with wall thicknesses up to 140 psf agreed with theory to within ± 15 percent (Reference 39). The theoretical dose angular distributions above an infinite fallout field, from which other penetration data are computed, and the dose rate variation with height are in good agreement with measurements in actual fallout fields in Nevada (References 30 and 31). The observed absolute dose rates, however, were an unexplained 30-40 percent less than the calculated values. Since publication of Spencer's work, the details of LeDoux's and Chilton's albedo approach to maze and duct computations have become available (Reference 40 and p. II-146 of Reference 34). Also, a method for calculating the contribution from ceiling shine has been proposed by Batter and Velletri (Reference 12). These authors found that ceiling shine, which is ground radiation reflected from the ceiling, is comparable in magnitude to skyshine and can be significant for certain buildings. Their computational procedure is in the form of the Engineering Manual method (Reference 3).

TABLE VII

Bibliography of PF Computational Methods

<u>Reference</u>	<u>Author</u>	<u>Organization</u> *	<u>Remarks</u>
32	Spencer	NBS	Monograph
3		OCD	Engineering Manual
34	LeDoux	KSU	Summer Institute, Part II
45	LeDoux	OCD	Equivalent Building Method
2		OCD	AE Guide
42 and 43	Spencer, Eisenhower	NBS	NFSS Computer Program
41		OCD	Shelter Design and Analysis, Vol. 1
47		British Home Office	British AE Guide
40	LeDoux, Chilton	NCEL	Gamma rays through ducts
46		Privy Council	Canadian AE Guide
12	Batter, Velletri	TO	Ceiling shine
48	Putz, Ruykendall	UC	Computer code using point-kernel method.

* For complete organization name, see indicated references.

C. Engineering Manual

1. Introduction

The OCD Engineering Manual (EM) method of computing PF's (References 3 and 41) was developed to provide a systematic and practical approach to analyzing complicated, realistic structures without neglecting significant features of the building-source configuration. (Successful use of the Engineering Manual requires about a two-week indoctrination course for practicing architects and engineers.) Its charts, other than Chart 9 (limited strip barrier factor), were derived from the basic attenuation data presented in Spencer's Monograph. Spencer later made calculations leading to Chart 9.

2. Experimental Confirmation of Engineering Manual Procedure.

The predictions of the Engineering Manual for above ground detectors in a multi-story windowless building in an infinite plane of radiation were experimentally confirmed by Tech Ops at their modeling facility (Reference 8). Data for limited planes were also obtained, but no comparisons with Engineering Manual calculations were presented. It is recommended that such a comparison be made to verify Chart 9 of the EM. Tech Ops also experimentally confirmed the computations for the effect of various arrangements of interior partitions (References 10 and 11). The dose rate measurements in the basement were higher than predicted; and the dose rate variation with depth below grade first increased, and then decreased, contrary to EM calculations. Qualitative explanations for this behavior are offered in Appendix M.

3. Ceiling Shine

The Tech Ops experiments on ceiling shine led to a proposed computational procedure (Reference 12) in the form of the Engineering Manual

method. In most shelters for which a large contribution arises from the roof, direct, or wall-scattered radiation, the present Engineering Manual method of including an estimate of ceiling shine in the directional response for skyshine, $G_a(\omega)$, is probably adequate, since the total ceiling shine contribution is only on the order of 10 percent of the total contribution. On an intermediate floor in a tall building with a large fraction of apertures, thick floors, and surrounded by tall buildings, the detector will not receive any direct radiation, skyshine, or much wall scatter radiation from the adjacent walls, and hardly any radiation from the roof or from the upper and lower floors. In this case the largest contribution will come from radiation from the finite plane entering the apertures and reflecting from the ceiling. It is therefore recommended that the ceiling shine procedure be included in the next revision of the Engineering Manual as an ancillary method for handling this class of configurations. When this procedure is employed, the ceiling shine correction in $G_a(\omega)$ must be removed if skyshine is computed (see p. II-66 of Reference 34 for this correction).

4. Azimuthal Sectors

The Engineering Manual makes use of the concept of azimuthal sectors in dealing with irregularities in source and building configurations. RTI found this concept to be a powerful tool in reducing the 33 buildings in the sample (see Chapter 4) to calculable arrangements. The azimuthal sector method has the potential for allowing significant improvements in the PF calculation for the majority of these buildings. The present method predicts that the off-center azimuthal sector of the finite plane of contamination in Figure 8a below will give the same dose rate

as a centrally located sector of the same angular size as in Figure 8b. The expected error in this assertion can be determined directly from data of a Tech Ops model (p. 28 of Reference 44), the plan view of which is shown in Figure 9. In this experiment, dose rate measurements were made 2.5 feet above the center of the first floor of a building with 80 psf walls. With equal source densities and equal areas in locations B and D, the ratio of the observed dose rates was

$$\frac{D_B}{D_D} = \frac{0.56}{0.29} = 1.93.$$

This ratio can be converted to a per-unit angle of azimuthal sector basis instead of a per-unit area basis by multiplying by $(\cos \theta_D)/(\cos \theta_B)$

$$\frac{D_{\theta B}}{D_{\theta D}} = 1.93 \times \frac{0.832}{0.975} = 1.65.$$

This result shows that an azimuthal sector $\Delta\theta$ centered about $\theta = 12.5^\circ$ will give a 65 percent larger dose rate than when centered about $\theta = 34^\circ$. For thicker walls and a larger range of θ 's, a wider variation in the dose rates will occur. This is due primarily to the slant penetration through the wall. As illustrated in the building example in Figure 5 of Chapter 4, most of the sources of contamination encountered in the 33 building sample were off-center finite planes rather than infinite planes, or were finite planes, such as a street, extending the entire length of a wall (this latter condition is the basis for Chart 9 of Reference 3). If contributions per degree from all sectors on a building side are about equal, this variation with sector will average out so that no improvement for slant penetration can be made to the Engineering Manual.

FIGURE 8

Plan View of Building Illustrating Azimuthal Sectors

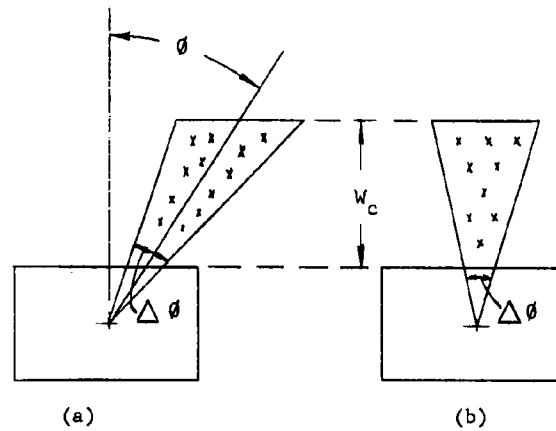
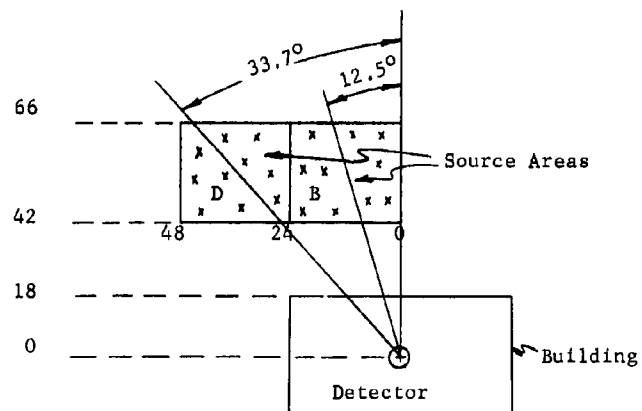


FIGURE 9

Plan View of Tech Ops Experimental Layout

(dimensions are in feet for scaled-up building)



However, it is not obvious from a visual inspection of Figure 5 in Chapter 4 that this is the case. It is therefore recommended that consideration be given to an investigation of the feasibility of incorporating some factor into the present Engineering Manual procedure to account for the variation in contribution of azimuthal sectors of identical size centered on different azimuthal angles.

D. Equivalent Building Method

A somewhat simplified method for computing PF's known as the Protection Factor Method (p. II-108 of Reference 34), also called the Equivalent Building Method (Reference 45), has been advanced by LeDoux. This method is an approximation based on a reformulation of numerous calculations from the Engineering Manual. In essence, mass thicknesses are adjusted in AE Guide-type (Reference 2) charts to account for departures from simple geometries, thus providing an improvement in accuracy of the straight AE Guide method, yet not requiring the tedium of a full Engineering Manual calculation. In comparisons with the illustrative examples in the Engineering Manual, this method generally yielded results which agreed within 10 percent. Whereas the Engineering Manual is very well suited for PF analysis, the LeDoux method offers advantages of speed and simplicity in synthesis when comparison of competitive specifications is involved. The latter method is more streamlined, yet has sufficient flexibility to determine the relative effectiveness of alternates in design.

E. AE Guide and NFSS Computer Program

The AE Guide (Reference 2), another approximation to the Engineering Manual which offers a quick answer for simple structures, formed the basis for the National

Fallout Shelter Survey Computer Program (NFSSCP) (References 42 and 43). In some cases the AE Guide is superior to the NFSSCP while for other cases the Computer Program is superior. For example, the AE Guide is better for sill height corrections, but the Computer Program is better for limited planes of contamination. The advantages and shortcomings of these methods are discussed in Chapter 7.

The experiments of Tech Ops showed that the NFSS Computer Program correction for near-field limited planes of contamination can lead to considerable error in the case of thick floors. These results are discussed in Appendix M, in which a recommendation is made to incorporate the Engineering Manual method in the next revision of the Computer Program.

A recommendation for handling cross interior partitions in the AE Guide, based on Tech Ops experimental observations (References 10 and 11), is made in Appendix N, and in Chapter 7 for use in the NFSS Computer Program. It is also recommended in Appendix N that additional experiments be conducted to investigate the effect of cross partition spacing on attenuation.

F. Canadian and British AE Guides

Reference 46 is the Canadian AE Guide which contains the same charts as Reference 2. The British Home Office also has prepared a document (see Reference 47) for PF computations. In a preliminary comparison of its predictions for a British house modeled by Tech Ops (Reference 18), the PF's were about 2 - 3 times those observed in the full-scale house and predicted by the Engineering Manual.

G. Point-Kernel Method

Another approach (Reference 48) which has been used for calculating dose rates for some structures at the Nevada Test Site (Reference 5) is that in vogue for nuclear reactor shielding analysis. It consists of summing the doses from representative point sources using the build-up factor concept to account for multiple scattering. The computed intensities from ground sources were about 90 percent

of the observed intensities for light shielding, and increased to 150 percent for heavier shielding. For roof sources, the percentage was 80 for light shielding and decreased for heavier shielding. These structures have also been analyzed by Eisenhower (Reference 49). The point-kernel method in Reference 48 has the flexibility of locating sources anywhere, thus being able to simulate non-uniform source distributions, airborne fallout, and a variety of as yet uninvestigated problems. It was used to determine the effects of interior partitions on the ground contribution (Reference 50) and to study the influence of roof pitch on the roof contribution (Reference 51). The chief disadvantages are that it is highly specialized, requires considerable computer time, and hence is not readily adaptable to wide-spread use. Unlike reactor problems, the fallout source extends over large (possibly unbounded) areas which require excessive geometrical ray-tracing.

V. WORK ON ELEMENTARY ABSORBER GEOMETRIES

The research reports of interest in evaluating PF calculations are categorized in Table VIII and listed in detail in the references at the end of this chapter. These categories are essentially elementary absorber geometries which can be superposed to represent realistic, complicated structures.

The subject of the effects of interfaces on gamma shielding has been recently reviewed by Clifford (References 52 and 53) and will not be discussed in detail here. His Technical Note contains 54 references. The open fox-hole experiments have dealt with skyshine and lip penetration. The latter contribution may turn out to be of importance in basements with adjacent limited planes of contamination. Under the vertical wall experiments in Table VIII could be listed some of the block house experiments. As mentioned earlier, the compartmentation experiments of Tech Ops have confirmed the azimuthal sector approach of the Engineering Manual for interior partitions. More experimental and theoretical work is needed on the in-and-down problem, which is concerned with dosages in basements from ground sources. Comparison of Engineering Manual PF's with measurements on actual buildings is made in Chapter 5. The modeling experiments of Tech Ops were discussed in Section II of this chapter and in Appendices L, M, and N. The fission spectrum data are summarized by Spencer (Part I of Reference 2). In addition to references previously reported, References 54 through 81 are included in Table VIII while other research of interest is listed under References 82 through 91. In addition to available new material, reports listed in Tables VII and VIII which are not discussed in previous sections of this chapter are being reviewed by RTI under a subsequent OCD research contract (OCD Sub-task 1115C).

TABLE VIII

Bibliography of Shielding Research

<u>Reference</u>	<u>Author</u>	<u>Organization</u> *	<u>Remarks</u>
DENSITY INTERFACE			
54	Berger	NBS	Monte Carlo
55	Ksanda, Moskin, Shapiro	NRDL	Ground roughness experiment
56	Rexroad, Schmoke	NDL	Buildup factors for point source on ground (full-scale experiment)
8	Batter, Starbird, York	TO	Buildup factors for point source on ground (experiment)
57	Clifford, Carruthers, Cunningham	DRCL	Simulated fallout field (full-scale experiment)
58 and 59	Clarke, Richards	AFSWC	
60	Titus	NBS	Dose near interface (published in Nuclear Science and Engineering)
30 and 31	Huddleston, Kinkaid, Burson, Klinger	EG&G	Dose angular distribution in actual fallout field
61	Mather	NRDL	Fallout spectra measurements
52	Clifford	DRCL	Review and bibliography
62	Clifford	DRCL	Ground roughness experiment
63	Kleinecke	UC	Monte Carlo

* For complete organization name, see indicated references.

(continued)

TABLE VIII (continued)

<u>Reference</u>	<u>Author</u>	<u>Organization</u>	<u>Remarks</u>
FOX HOLE EXPERIMENTS			
64	Clifford	DRCL	Lip contribution
34		KSU	Summer Institute, Part III
65	Schumchyk, Tiller	NDL	Lip contribution
1	Clarke, Batter, Kaplan	TO	Pumped source technique
VERTICAL WALL			
66 and 67	Dahlstrom, Thompson	NRDL	Angular distributions experiment
68	Plummer		Geometry and barrier attenuation experiment
COMPARTMENTATION EXPERIMENTS			
34		KSU	Summer Institute, Part III
	Kreger	NRDL	See p. I-5-10 of Reference 34
10 and 11	Starbird, Velletri, MacNeil, Batter	TO	Interior partitions in model building
69	Tomoeda, Hastings, Shumway	NRDL	Steel box
BLOCK HOUSE EXPERIMENTS			
34		KSU	Summer Institute, Part III
39	Schmoke, Rexroad, Tiller	NDL	Single-story windowless full- scale building
8	Batter, Starbird, York	TO	Multi-story windowless model building with limited planes
38	Schmoke, Rexroad	NDL	Roof contribution (full-scale)
17	Batter, Starbird	TO	Full-scale, ground contribution

(continued)

TABLE VIII (continued)

<u>Reference</u>	<u>Author</u>	<u>Organization</u>	<u>Remarks</u>
IN-AND-DOWN EXPERIMENTS			
70	Batter	TO	Scattering of Co-60 from plane source
8	Batter, Starbird, York	TO	Model building basement measurements
34		KSU	Summer Institute, Part III
ROOF CONTRIBUTION			
71	Berger, Lamkin	NBS	Calculation of roof and sky-shine contributions
72	Chilton, Saunders	BuDocks	Below ground full-scale structure calculations
73	LeDoux	USNCEL	Buried full-scale shelter calculations
74	LeDoux, Donovan	USNCEL	Underground full-scale shelter calculations
51	Schlegel	UC	Full-scale effect of roof pitch calculations
75	Titus		Fallout on concrete experiment
SHIELDING EXPERIMENTS AND ANALYSES			
48	Putz, Kuykendall	UC	Calculations for comparison with measurements in residential structures
5	Auxier, Buchanan, Eisenhower, Menker		Measurement in houses in fallout field
49	Eisenhauer	NBS	Calculations for comparison with measurements in residential structures
28	Burson, Borella	EG&G	Experiment with earth covered shelter
1	Clarke, Batter, Kaplan	TO	Pumped source experiment with full-scale structure

(continued)

TABLE VIII (continued)

<u>Reference</u>	<u>Author</u>	<u>Organization</u>	<u>Remarks</u>
SHIELDING EXPERIMENTS AND ANALYSES			
6	Batter, Kaplan, Clarke	TO	Pumped source experiment with concrete office building
27	Burson, Parry, Borella	EG&G	Pumped source experiment with residence
76	Malich, Beach	NRL	Experiment with barracks and underground shelter
77	Vortman	Sandia	Dose penetrating shelters exposed to explosion
29	Burson	EG&G	Pumped source experiment with four Los Angeles structures
78	Strickler, Auxier	ORNL	Experiment with Oak Ridge residences
79	Shumway, Miller, Plummer	NRDL	Experiment with underground shelter
80	Haggmark	NRDL	Comparison of calculations with experimental results for ships
26	Borella, Burson, Jacovitch	EG&G	Experiment on BNL Medical Research Center
81	Stewart		Brick house experiment
MODELING EXPERIMENTS AND ANALYSES			
	Tech Ops - see text		
	Kreger	NRDL	See p. I-5-14 of Reference 34 and p. 78 of Reference 37

VI. SUMMARY AND RECOMMENDATIONS

The roof contribution and infinite plane contribution predicted by Spencer's Monograph (and hence, the Engineering Manual method) for a concrete block house have been experimentally confirmed. The model building experimental dose rates from finite planes of contamination indicate that the NFSS Computer Program and AE Guide need revision. For unexposed basements, the experimental dose rate is higher than predicted by the Engineering Manual. Measurements of dose angular distributions support the use of an effective height in treating ground roughness. A new procedure based on experimental results is available for calculating ceiling shine. The Engineering Manual method of azimuthal sectors is adequate for handling interior partitions.

A summary of recommendations made in this chapter and Appendices L, M, and N as a result of the research review are:

1. It is recommended that penetration data such as that presented in the charts in the Engineering Manual be developed for the radiation of cobalt-60 and attenuation characteristics of steel.
2. It is recommended that Tech Ops limited strip (plane) data be compared with Engineering Manual calculations.
3. It is recommended that the Tech Ops' procedure for computing ceiling shine be incorporated in the Engineering Manual to be used for the class of configurations described in Section IV.
4. It is recommended that an investigation be made of the influence on the wall barrier factors of slant penetration of radiation through walls in off-center azimuthal sectors.
5. The limited plane data of Tech Ops model experiments shows that the NFSS Computer Program will give considerable error for thick

floors. It is recommended that the Engineering Manual procedure of computing contribution from limited planes of contamination be incorporated in the next revision of the Computer Program.. The details of implementing this revision appear in Chapter 7 and Appendix P.

6. It is recommended that the next revision of the AE Guide carry the instruction in Section II. B. 2 of Appendix N for treating cross partitions.
7. It is recommended that additional experiments be conducted to investigate the effect of cross partition spacing on attenuation (see Appendix N).
8. It is recommended that an investigation be made of the discrepancy between experimental and theoretical ground contribution to an unexposed basement.

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Chapter 7

NBS-NFSS Computer Program Modifications

I. INTRODUCTION

This chapter contains the recommendations of the Research Triangle Institute for modifying the existing NBS-NFSS Computer Program (Reference 1) used to compute building protection factors (PF). The majority of the recommendations contained herein were reported to OCD on 19 April 1963 in RTI Research Memorandum RM 81-5 (Reference 2). Details of the recommendations and their justification are contained in Appendix P.

The procedures used in the present program are based on the Guide for Architects and Engineers (Reference 3) which gives very conservative building PF's. It is generally concluded by personnel engaged in fallout shielding research that the Engineering Manual method (Reference 4) of calculating PF's gives more accurate results; therefore, the recommended changes are those which bring the NBS-NFSS Computer Program nearer to the Engineering Manual method. These changes are based on findings from the analysis of NFSS data, the categorization of building characteristics, the comparison of experimental and calculated radiation contributions in both model and full-scale structures, and the review of other research conducted in the field of fallout radiation shielding. Only procedures which could be accomplished with Phase 1 and Phase 2 NFSS data were considered.

II. RECOMMENDATIONS

The recommendations for changes in the NBS-NFSS Computer Program are as follows:

1. Basement Exposure - The contribution from the exposed portion of a basement wall is presently computed by multiplying the fraction of exposure by a value from Table 3 of the NFSS Computer Program (Chart 3, Reference 3), which includes a contribution from direct radiation. This procedure also assumes that apertures extend from the basement floor (not the grade level) to the ceiling. To correct for these limitations, Engineering Manual procedures using aperture sill height data from Phase 2 to supplement Phase 1 data are recommended. These procedures will eliminate the excessive direct radiation now included and will allow more accurate treatment of finite planes of contamination. For a 5000-square-foot basement with 80 psf walls, 37.5 percent exposure, no apertures, and infinite planes of contamination, these recommended Engineering Manual procedures result in a 20 percent reduction in the computed contribution from the exposed basement wall.
2. Roof Contribution - Present NBS-NFSS Computer Program procedures for calculating the contribution from the roof of a building give results very close to Engineering Manual procedures for square buildings. They do not, however, account for variations in contribution because of shape as can be done by Engineering Manual procedures. For example, in a 40 foot x 160 foot building with 30 psf floors and roof, a 14 percent reduction in contribution at the third story below the roof is found when Engineering Manual procedures are used.

The Engineering Manual procedure is therefore recommended for calculating main roof and setback roof contributions for all buildings without interior partitions and for those with partitions reported in Phase 1. Interior partition data from Phase 2 are not recommended for use in calculating roof contribution at this time. For buildings without the identical partition placement reported for each floor in Phase 2, too many manipulations are required to justify machine programming.

3. Ground Contribution to Stories Above Grade - The major limitations of the present NBS-NFSS Computer Program in calculating ground contribution are that no correction is made for aperture sill height and no reduction for radiation shielded by the floor slab is made. In order to properly correct for the difficulties outlined above, it is recommended that the Engineering Manual (EM) method be used in computing ground contribution to stories above grade.

Present Phase 1 input data, plus the aperture sill height data from Phase 2, are adequate for the ground computational procedure if the apertures are assumed to extend from the reported sill level to the ceiling. In addition to improving the calculation of ground contribution through apertures by more than 50 percent in some buildings, the EM method will allow for more adequate handling of variable story heights and rectangular building shapes. Finite planes of contamination will be handled in the usual EM method by differencing the ground contribution directional responses.

4. Areaways - Areaway data were recorded in the NFSS Phase 1 only if they exceeded 50 percent of the length of the adjacent wall. They were then counted as the first plane of contamination on that side, and their effect had to be computed as if they were a minimum of 10 feet wide. An areaway, with apertures, adjacent to 50 percent of one exterior wall in an otherwise unexposed basement (see TAB 9 of Appendix P) will almost double the total ground contribution and therefore should be included in the PF computation. This is one case in which the present NFSS Computer Program is not conservative. It is recommended that the portion of basement wall with an adjacent areaway be considered as the first floor, with the bottom of the areaway as the first plane of contamination and the normal grade level as the second plane. The contribution from this finite plane of contamination will be calculated by the EM method, in which directional responses for direct and scattered radiation are differenced. The ratio of the areaway length to the wall length would then be used to determine the percentage of this contribution to be used in the total wall contribution. Data for this Engineering Manual calculation of areaway contribution are available from the Phase 2 Data Collection Form (DCF).

Details of these recommendations, including functional equations, tables representing Engineering Manual Charts, the detailed steps necessary to make hand calculations compatible with machine computations, and numerical examples are found in Appendix P.

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Chapter 8

Survey of Potable Water Available in a Sample of 33 Buildings*

I. INTRODUCTION

As part of OCD Project 1115A, the Office of Civil Defense asked RTI to obtain information on the amount of potable water already "trapped" by plumbing, holding tanks, etc., in the statistical sample of buildings used by RTI (see Chapter 4) to study other NFSS characteristics. All drinkable water that was contained and covered (i.e., suitable for drinking in a fallout situation) was recorded. The containers were divided into various categories such as hot water tanks, pressure tanks, sprinkler system storage, etc., with capacity and number being recorded.

* The data presented in this chapter were originally reported to OCD on 7 June 1963 as part of RTI Research Memorandum RM 81-6 (Reference 1).

II. SAMPLE CHARACTERISTICS

The number of buildings in the sample was 33. The sample was drawn randomly from all buildings in the National Fallout Shelter Survey that contained at least one shelter area in PF Category 2, 3, or 4 and were located in the forty largest cities in the United States. The details of sample selection are given in Chapter 4 and Appendix F. The buildings were spread throughout the eight OCD regions. The median building height was six stories, with the highest being twenty-eight stories and the smallest only two stories. Thirty of the buildings had at least partial basements, but only four had sub-basements. Sixteen buildings were primarily apartments, ten were offices or stores, four were schools (or recreation facilities), and three were manufacturing plants or warehouses. The PF Category 4 - 8 shelter capacity of these buildings varied from zero to almost 40,000 spaces.

Table IX gives a summary of some additional characteristics of the individual buildings in the sample and Table X lists the shelter capacity (PF Category 4 or better) and potable water trapped in each shelter.

TABLE IX

RTI 33 Building Sample

<u>Number</u>	<u>City</u>	<u>OCD Region</u>	<u>Standard Location</u>	<u>Facility Number</u>	<u>Stories</u>	<u>Const. Date</u>	<u>Use*</u>
1	Boston, Mass.	1	1315-0026	03130	3 B**	1906	Rec.
2	Newark, N. J.		1541-0066	00984	13 B	1953	Apt.
3	Bronx, N.Y.C.		1641-0046	00923	5	1940	School
4	Bronx, N.Y.C.		1641-0138	03782	6 B	1935	Apt.
5	Bronx, N.Y.C.		1641-0194	01907	6	1920	Apt.
6	Brooklyn, N.Y.C.		1642-0207	03232	4 B	1923	Apt.
7	Brooklyn, N.Y.C.		1642-0495	04335	4 B	1890	Apt.
8	Manhattan, N.Y.C.		1644-0028	01072	15 B	1898	School
9	Manhattan, N.Y.C.		1644-0063	02527	9 B	1936	Whse.
10	Manhattan, N.Y.C.		1644-0096	02947	25	1954	Office
11	Manhattan, N.Y.C.		1644-0126	00858	6 B	1905	Apt.
12	Manhattan, N.Y.C.		1644-0156	01917	17 B	1928	Apt.
13	Manhattan, N.Y.C.		1644-0204	03371	7	1933	Apt.
14	Manhattan, N.Y.C.		1644-0260	01773	8	1930	Apt.
15	Queens, N.Y.C.		1645-0017	00764	6 B	1939	Apt.
16	Queens, N.Y.C.		1645-0538	07616	7	1951	Apt.
17	Rochester, N.Y.		1651-0005	00598	4 B	1866	Store
18	Washington, D. C.	2	2211-0005	00511	7 B	1920	Apt.
19	Washington, D. C.		2211-0062	03448	8 B	1936	Office
20	Louisville, Ky.		2351-0029	01973	3 B	1870	Apt.
21	Cleveland, Ohio		2541-0058	01272	22 B	1924	Office
22	Philadelphia, Pa.		2675-0017	01738	17 B	1917	Apt.
23	Memphis, Tenn.	3	3731-0043	01301	6 B	1914	Mfg.
24	Chicago, Ill.	4	4121-0065	02101	3 B	1920	Apt.
25	Chicago, Ill.		4121-0144	03302	8 B	1913	Office
26	Chicago, Ill.		4121-0490	06068	27 B	1960	Office
27	Chicago, Ill.		4121-0868	06023	2 B	1950	Apt.
28	Indianapolis, Ind.		4241-0013	01003	2 B	1915	School
29	Houston, Texas	5	55B1-0026	06118	3 B	1913	Store
30	St. Louis, Mo.	6	6434-0122	01971	28 B	1925	Office
31	Los Angeles, Calif.	7	7231-0453	01427	12 B	1922	Office
32	San Francisco, Calif.		7274-0072	05214	5 B	1924	Mfg.
33	Seattle, Wash.	8	8521-0061	01462	8 B	1924	Office

* primary use

** B indicates basement

TABLE X

Trapped Potable Water and Shelter Space in Sample Buildings

<u>Number</u>	<u>City</u>	<u>Potable Trapped Water (gallons)</u>	<u>PF Category 4 - 8 Spaces</u>	<u>Gallons per Space</u>
1	Boston, Mass.	6,016	76	79
2	Newark, N. J.	2,676	41	65
3	Bronx, N.Y.C.	3,035	2,207	1.4
4	Bronx, N.Y.C.	2,800	541	5.2
5	Bronx, N.Y.C.	0	0	-
6	Brooklyn, N.Y.C.	0	0	-
7	Brooklyn, N.Y.C.	0	2	0
8	Manhattan, N.Y.C.	10,120	1,682	6.0
9	Manhattan, N.Y.C.	44,000	579	76
10	Manhattan, N.Y.C.	37,000	5,999	6.2
11	Manhattan, N.Y.C.	2,234	8	280
12	Manhattan, N.Y.C.	16,480	428	38
13	Manhattan, N.Y.C.	0	45	0
14	Manhattan, N.Y.C.	5,000	0	-
15	Queens, N.Y.C.	140	0	-
16	Queens, N.Y.C.	3,500	18	195
17	Rochester, N. Y.	683	97	7.0
18	Washington, D. C.	1,935	442	4.4
19	Washington, D. C.	27,190	32,284	0.84
20	Louisville, Ky.	24	4	6.0
21	Cleveland, Ohio	16,184	39,421	0.41
22	Philadelphia, Pa.	5,194	23	226
23	Memphis, Tenn.	29,661	63	470
24	Chicago, Ill.	Access Denied	-	-
25	Chicago, Ill.	35,033	3,362	10.4
26	Chicago, Ill.	5,200	8,747	0.60
27	Chicago, Ill.	136	0	-
28	Indianapolis, Ind.	1,041	0	-
29	Houston, Texas	648	100	6.5
30	St. Louis, Mo.	39,627	1,705	23
31	Los Angeles, Calif.	2,574	1,259	2.0
32	San Francisco, Calif.	67	42	1.6
33	Seattle, Wash.	486	1,623	0.3
		298,684	100,798	Avg. 2.96

III. FINDINGS

Data on trapped water were obtained from 32 of the 33 sample buildings (access denied in one) and were divided into the following categories:

- A. Fire Control Tank
- B. Sprinkler System
- C. Hot Water Heater (Tank)
- D. Supply Pipe
- E. Holding Tank
- F. Water Closet Flush Tanks
- G. Air Conditioner (non-treated)
- H. Heating Tank (non-treated)
- I. Indoor Swimming Pool
- J. Miscellaneous

Table XI gives a summary of the number of buildings in the sample that had containers of the type listed above (A-J) and Appendix K contains the detailed potable water data for individual buildings. It is interesting to note that one-half of the buildings had large hot water tanks and/or holding tanks.

The amount of potable water trapped in the sample buildings varied from zero to 44,000 gallons. A listing of the water data and shelter space per building is given in Table X. A measure of the usefulness of this water is the amount available per shelter space (PF Categories 4-8); this varies quite markedly from building to building. Table XII presents a summary of trapped water and shelter space. Although the largest number of buildings were in the 5-25 gallons-per-space category, about 80 percent of the shelter space is in the 0.2-1.0 gallon-per-space category, because the two largest buildings in the sample fell in this category.

In the collection of water information, items containing an insignificant number of gallons, such as small pipes, were ignored.

TABLE XI

Storage Container Summary

	<u>Buildings</u>
Fire Control Tank - - - - -	7
Sprinkler System- - - - -	4
Hot Water Tank (> 200 gal.)- - - - -	17
Hot Water Tank (< 200 gal.)- - - - -	9
Supply Pipe - - - - -	2
Holding Tank- - - - -	12
Water Closet Flush Tanks- - - - -	8
Air Conditioning Tank - - - - -	0
Heating Tank - - - - -	3
Indoor Swimming Pool - - - - -	0
Miscellaneous - - - - -	6

TABLE XII

Potable Trapped Water per Shelter Space in Sample Buildings

<u>Gallons/space (PF Cat.4-8)</u>	<u>Buildings</u>	<u>Total Spaces (Cat.4-8)</u>
Zero - - - - -	4 - - - - -	47
0.2 - 1.0 - - - - -	4 - - - - -	82,075
1 - 5 - - - - -	4 - - - - -	3,950
5 - 25 - - - - -	7 - - - - -	13,490
25 -100 - - - - -	5 - - - - -	1,124
100 -500 - - - - -	4 - - - - -	112
No PF Category 4 or better shelter - - - - -	4 - - - - -	0
		<u>100,798</u>

IV. RELATED STUDY BY GUY B. PANERO, INC.

Guy B. Panero, Inc., surveyed the potable water available in the "interior building plumbing" for buildings in Springfield, Massachusetts (Reference 2) and reported 12.3 gallons per PF Category 4-8 shelter space. The Panero study was for one city only and contained no extremely large structures. The RTI sample was drawn from the 40 largest cities in the country and two of the buildings contained 71 percent of the sample shelter spaces and only 14.5 percent of the available water. Without these two buildings, the gallons per shelter space in the RTI survey would increase to 8.77.

In addition to water trapped in buildings, Guy B. Panero also determined the water available in surge tanks, distribution reservoirs, filters, and supply and distribution piping (Reference 2).

V. SUMMARY AND CONCLUSIONS

Since this sample of NFSS structures is quite small and the water information was collected as a secondary objective of a survey to determine reliability of NFSS PF results, estimates of national results are only approximate. It does appear, however, that the amount of potable water that is "trapped" in NFSS buildings containing fallout shelter is in many cases sufficient to supply the emergency water needed (3.5 gallons per person for 14 day supply) and is thus a factor to be considered before stocking of water containers is undertaken. This conclusion is significant because full personnel capacity cannot be realized in many shelters due to limited storage space for the shelter supplies.

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OCD Sub-task 1115A - Final Report R-OU-81, Part I
Analysis of Survey Data. Edward L. Hill et al.
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